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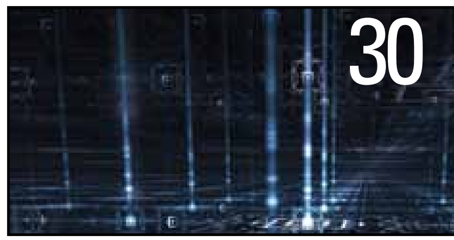

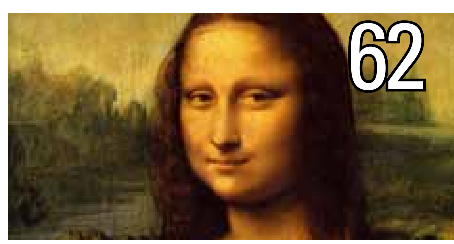

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By the time this letter is being written, it is already November. Yes, this issue was scheduled later than usual in order to keep the news and events current, and which better event to wait for, than the Annual SAIEE Banquet?

And what an event it was – we hosted the 104th banquet, and it was a bit different from the usual. We had prizes to the value of R112 000 to give away and I must admit, there is no better feeling in the world, than the feeling of giving.

It is therefore with pride, that I 'give' you the November issue, featuring Electronics and Mechatronics.

Our feature articles starts off on page 22, where you can learn how to charge supercapacitor banks for energy storage.
Page 30 informs you of Systems Engineering, whereby mechatronics and software needs to be developed closely together.

Dudley Basson wrote an amazing historical article, "From Kettles to Supercritical" – shedding more light on various aspects of science and inventions.

Congratulations go out to the team of Impact Energy, who won the **watt**now Advertiser of the Year Award, three times in a row. Thank you for your continued support.

Well, this being the last issue of **watt**now for 2015, I would like to take this opportunity to wish you, my reader, and your family the very best and safe festive season.

Thank you for being a part of the **watt**now magazine. Your comments, letters, phone calls and most of all, your article contributions make the **watt**now what it is.

Herewith the November issue, enjoy the read!

Minx

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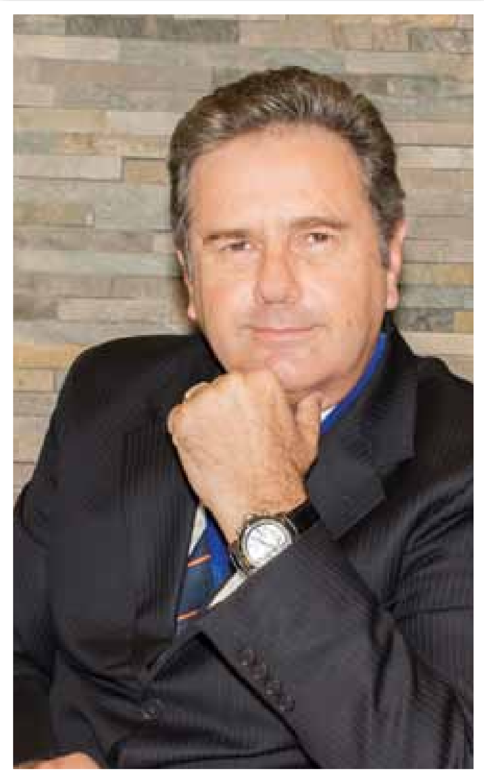


André Leo Hoffmann
2015 SAIEE President

It's been a while since I last hung up my soldering iron, stepped out of my 'hobby-shack' in the basement of my parent's home and left all my 'bread-board' designs, multi-meter, oscilloscope and components to gather dust. Such is the lifecycle of the engineering technologist as a career takes shape and we get caught up in other activities that make up our lives.

The electronics industry in South Africa has been under pressure for some time, as global competition has taken its toll on the local manufacturing sector. It is worth mentioning that South Africa has historically made significant contributions to Research, Development and Engineering (RD&E) at international level. For instance, it was Dr van der Bijl who first established the formula for Thermionic triode vacuum tubes or 'valves', and designed many of the valves used in the early days. He was also involved in the development of multiplex for wireless telegraphy and telephony, and scrambled telephone speech. (Sparkling Achievements P14).

Personally, being part of the Telecommunications industry, I have witnessed the significant growth of electronics manufacturing to support this industry, particularly from 1980 onwards. With companies like such as ATC (in Brits) and Alcatel Altech Telecoms (AAT) (previously Standard Telephones and Cables (STC)), whose factories I visited at different times in my career. It was pioneering R&D and factories such as these that built the telecoms network in South Africa at that time, component by component, and gave us the legacy from which Telkom South Africa has emerged and built on.

This was significantly ramped up from 1994 to get telephony reach to more of the population, and the Wireless Local Loop programme was initiated and accelerated. As a result, a self-contained surface mount production facility was installed at AAT in record time to manufacture 600 Digital Enhanced Cordless Telephone (DECT) subscriber units per day. These machines could mount some 43 000 surface mounted components per hour onto DECT circuit boards. The legacy of this factory survives in the hundreds of people who learned about telecoms production, and the thousands of operators who received training and employment.

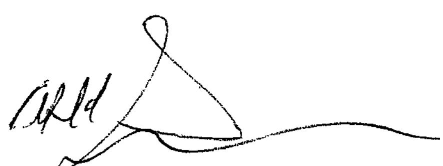
The AAT legacy was further entrenched by the establishment of the Engineering Design Laboratory, which grew rapidly to well over 100 engineers, technicians and support staff. They produced many brilliant engineers who went on the command senior positions, both locally and overseas. The Lab was often referred to as the 'nursery school' of telecoms in South Africa (ibid P51).

Other factories such as TEMSA (Telephone Manufacturers of South Africa - later Marconi) and others also made significant contributions to the electronics manufacturing capacity in South Africa at the time.

Things have changed significantly since then, and South Africa has been thrust into global environment. Yet in the ICT industry, South African companies are among the world leaders in pre-payment, revenue management and fraud prevention systems, as well as in the manufacture of set-top boxes. These are successfully exported to the rest of the world. According to the Electrotechnical Export Council (SAEEC), the sector has developed a competitive advantage by being flexible and adaptable in its manufacturing approach. Opportunities lie in the local assembly of green-energy technologies for electronic components and subassemblies and the development of access-control systems and security equipment, automotive electronic subsystems, systems and software development in the financial services sector, integrated circuits and solar cells. There are also significant opportunities for the export of hardware and associated services, and peripherals.

All this of course is dependent on competent technicians, technologists and engineers to maintain the momentum and capacity of our Electronics and Megatronics capability.

Thank you for your support as we #Payitforward



André Hoffmann
Pr. (Tech.) Eng | FSAIEE

WATTSUP

SAIEE Annual Banquet

The SAIEE recently held its 104th Annual Banquet at the Birchwood Hotel & OR Tambo Conference Centre.

At this auspicious event, the SAIEE recognised individuals who made a difference in their professions during 2015.

The SAIEE Engineer of the Year award, sponsored by Actom, recognizes a SAIEE member who has energetically and voluntarily worked towards promoting electrical science and its applications for the benefit of SAIEE and the South African community. This award is sponsored by Actom, and was presented by Tembela Caza. The 2015 SAIEE Engineer of the Year is Prince Moyo.

Prince is a Fellow of the SAIEE, a SAIEE Council Member and is currently the Chairman of the Membership Committee. In addition, he is a member of the SA Committee of the IEC and is secretary of the SA Committee of Cigre. Prince graduated with a BSc Engineering Honours degree in 1993. He became an SAIEE member in 1997 and registered with ECSA as a Professional Engineer. He completed his Masters Degree in Science in Engineering at Wits University in June 2001.

In December 2010, Prince became a Fellow of the SAIEE and is now General Manager: Transmission and Distribution Engineering at Eskom, where he has been employed for the last 18 years. Prince has made significant contributions on the committees he has served and is renowned for his original and innovative thinking, much of this to the benefit of the Institute and its members.

The Keith Plowden Young Achievers award is for engineers 35 years or younger who have achieved significant levels of innovation, contributions to the fraternity and improved productivity and enhancement to the quality of life by engineering work.

This year the deserving candidate was none other than Elekanyane (Ele) Ndlovu. This award, sponsored by Powertech Transformers, was presented by Bernard Meyer, CEO, Powertech. Ele is the ideal candidate as she has a BSc Eng from UCT, and she has excelled in her work. She serves on the SABS Board of Directors and is a SABS Commercial non-executive Director, Chairman of SABS Social Ethics Committee and serves on numerous committees dealing with energy conservation, Protection/Telecommunication, metering and Control of Systems.

From left: André Hoffmann (SAIEE President) with Prince Moyo, SAIEE Engineer of the Year winner and Tembela Caza from Actom.

From left: André Hoffmann (SAIEE President) with Sunil Maharaj, SAIEE Engineer of the Year winner and Tembela Caza from Actom.

From left: André Hoffmann (SAIEE President) with Elekanyane Ndlovu, Keith Plowden Young Achievers Award winner and Bernard Meyer, Powertech.

The President's Award, sponsored by ABB South Africa was presented to Dr Bernard "Bernie" Lewis Fanaroff. The South African born Astronomer has played a significant role as Director in the huge international Square Kilometre Array (SKA) project, where SA is a major player in the world's largest radio telescope ever.

Bernie has been recognised through receiving many awards. In 2013 he was awarded the Order of Mapungubwe, which is South Africa's highest honour awarded to a South African citizen for excellence and exceptional achievement. This is particularly for his part in securing the African share of the SKA Project.

At all these award ceremonies, Dr Fanaroff has emphasized the contribution of his team and that they all share these achievements.

The SAIEE is honoured to be able to make this award to one who has achieved much in elevating our country to great heights among nations, and yet is so humble.

The Engineering Excellence Award recognizes a Member of the Institute who has excelled in Electrical Engineering. This year, the award was sponsored and presented by Hendrik Spies of Doble Engineering, and it was awarded to Prof Sunil Maharaj. Prof Maharaj, recently appointed Dean of the Faculty of Engineering, Built Environment and Information Technology at the University of Pretoria Engineering University, and formerly the Head of Department Electrical Engineering, has been a long-standing member of the SAIEE since 1996. He was elected to Fellow early in 2014 while serving on Council.

Sunil sports a BSc Electronic from UKZN, two MSc degrees from UKZN and from the University of Coventry UK. In addition he has a Project Management Diploma and a PhD Wireless Communications from the University of Pretoria. One might deduce this is a pure academic and one would be wrong – Sunil has worked for Siemens in SA and Germany for 5 years before entering the academia arena. His rapid rise from a Post Grad Research Assistant at the University of Natal in 1988 to Head of Department at University of Pretoria in 2014 is evidence of his value to the engineering profession. A truly deserving recipient of this award - and given his extraordinary work ethic - this will not be the last Award.

The 2015 Advertiser of the Year Award winner, for three years running, is Impact Energy. Impact Energy (Pty) Ltd was formed five years ago by a group of companies and individuals who have been participating in energy optimisation and supply projects within their own client base. They identified the need for advanced power quality hardware that would compensate for load variations in real time. None was on offer in the African market at that time. Their search led them to partnering with Elspec Engineering Ltd. The father and son team, Wayne & Den Bromfield received the award on behalf of their company.

From left: Dr Bernard Fanaroff received the President's Award from André Hoffmann (SAIEE President).

Advertiser of the Year Award winners.
From left: Wayne Bromfield (Impact Energy), Minx Avrabos (wattnow), Den Bromfield (Impact Energy) and Dr Hendri Geldenhuys, Chairman (Publications Committee).

André Hoffmann with MC of the evening, Ian McKechnie.

SAIEE Annual Banquet (continues...)

André Hoffmann with members who received their 50 year membership certificates.

The annual Banquet would not have been such a success without our sponsors. We had a total of R112 000 in prizes to give away on the evening. Our 2015 SAIEE President, André Hoffmann and his lovely wife, Janine Meyer-Hoffmann, drew the names out of a box. All the guests present had a chance of winning one of the 28 prizes. We would like to thank the following sponsors: ABB, Actom, Africa Albida, Bayshore Inn, Bellevue Wine Estate, Beverly Hotels, Bergman Fisher Associates, Boyang Gape Tours & Travels, Doble Engineering, Fairmont Hotel & Resorts; Kenia, Houghton Golf Club, Indaba Hotel, Spa & Conference Centre, kulula.com, Legend Hospitality Group, Leriba Hotel Group, Mowana Spa, Octavia's Day Spa, Piatto restaurant & grill, Powertech Transformers, Premier Hotels & Resort, Protea Hotel Hazyview, Rainbow Tourism Group Ltd, SAB World of Beer, Schneider Electric, Shumani Mills and Sun Internatiomal.

From left: Gerda Geyer, Janine Meyer-Hoffmann, Larry Soffer, Minx Avrabos and André Hoffmann.

Our entertainer for the evening, mentalist extraordinaire, Larry Soffer, blew the minds of our guests. Larry performed his magic and mentalism in the hands of our guests, using cards, coins, jewellery and other props. He made objects move and levitate without touching it. He read minds and bent metal objects such as coins, keys and forks – he even had sceptics guessing.

Judging by the huge smiles on our guests' faces, the evening was truly a successful event.

Guests of the University of Pretoria with Sunil Maharaj (middle).

A few of the Centre Chairman with SAIEE President.
From left: Zola Ntshangase (KZN Centre), Maanda Ramatumbu (Gauteng), Dr Ben Kotze (Central), André Hoffmann, Andy Falkoner (Eastern Cape), Ludolph de Klerk (Mpumalanga) and Bruce Thomas (Western Cape).

Members of the Gauteng Centre with André Hoffmann.

André Hoffmann with the organizers of the banquet, Minx Avrabos and Gerda Geyer.

Ansie Smit with grandson, Jacques Smit

André Hoffmann and Larry Soffer (Mentalist)

Gerda & Anton Geyer

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Ground breaking initiative for workplace training

Picture at the Eskom signing (from left): Ms Lebogang Molatlhwe (Senior Manager: Skills Development CoE (acting), Matome Makwela (GM HR Eskom), Jacob Machinjike (GM Transmission Grids, Eskom) & Len Turner (Senior Consultant: Skills Development Centre of Expertise).

Picture at the SAIEE signing (from left) seated: Jacob Machinjike (GM Transmission, Eskom) & Stan Bridgens (CEO, SAIEE). Back (from left): André Hoffmann (SAIEE President), Dr Pat Naidoo (Immediate Past President, SAIEE) & John Gossling (SAIEE).

The brainchild of SAIEE Immediate Past President, Dr Pat Naidoo to find a breakthrough to train graduates in the work place by initiating cooperation between Eskom, SAIEE and Tertiary Institutions who provide the technician and technologist courses.

To qualify for the Technicians and Technologist diplomas requires periods of Work Place Learning (WPL) training known as P1 and P2 for 12 months. Diplomas are only awarded when students have successfully completed and passed the P1 and P2 of WPL.

The dearth of opportunities to complete the WPL have left Learners stranded with having completed the academic part of their course and not qualifying because they cannot get the WPL side of the qualification.

The breakthrough to overcome this barrier is based on a tripartite agreement (MoU) between an employer to provide the opportunity for training in their normal operations, a professional body to mentor and liaise and the respective tertiary institution to assess and award the diploma. The most important part is the agreement with the student to commit and undertake the WPL without remuneration at the outset.

Festo delivers pioneering automation technology through increased distribution network.

Leading supplier of innovative automation technology, Festo South Africa, have expanded their vast network of product dealers and customer interaction points to ensure greater access to their products and services. The shift in the company's business model will lead to a 20% increase in Festo's customer facing sales force and a reinvestment of over R7.5 million in sales resources.

Festo has invested substantial resources in the development of a market-leading online store, contact call centres, and direct deliveries. Recently, Festo South Africa reaffirmed their expansive strategy with the inclusion of Bearing Man Group (BMG) as one of their official logistics distributors.

The addition of BMG as an authorised distributor provides for an increase in customer interaction points throughout South Africa and Africa, ensuring customers have easier access to world class logistics, ample stock supplies and market-leading technical expertise.

With the inclusion of BMG, Festo products are now distributed through 12 BMG stores in South Africa's major cities, 150 local distributors nationwide and almost 200 throughout Africa.

Describing the expanded sales network, Warren Harvard, National Sales Manager for Festo, stated, *"Our aim is to provide customers with more access to Festo products and services. Our increased distribution network will benefit those customers who prefer walk-in purchase points, while those who still wish to place an order over the phone or through our website and receive next day delivery, will still enjoy the same service."*

"Our additional distribution spaces allow us to commit our resources to ensure gains in efficiency. This will mean that point-of-sale facilities are no longer required in some of our branches so we are deliberately reinvesting these resources in Sales Engineers and our Didactic training facilities, resulting in a significant increase in our sales force and affording our customers with more time and access to our Engineering support team."

The increase in distribution channels supports Festo's long-term business strategy. *"Ultimately we want to grow. Over the last 40 years, Festo has grown steadily within the South African market and we intend to continue that growth over the next 40 years. To achieve this we recognised the real need to ensure our products become more widely accessible through increased interaction points for our customers, while at the same time investing resources in our online distribution and Didactic training services"* Harvard explained.

In working with BMG and Festo's local distributors, the company is able to offer customers an immense range of products and support services, with ease.

"We have regional Sales Engineers at the local level to help upscale customer knowledge and skills while also providing product training and support to the sector. We have always taken pride in being able to offer unique services, specialised technical support, and efficient logistical processes that allow customers to fully access and utilise the world's best automation technologies. Now, with our increased distribution network, we are able to do more with our resources and ensure that our customers receive the best possible products, support and training so that they are able to enhance their own business interests," Harvard stated.

Gartner Names Schneider Electric in its Top 15 2015 European Supply Chain Organizations

Schneider Electric, the global specialist in energy management and automation, today announced that Gartner, Inc., the leading provider of research and analysis on the global information technology industry, has rated the company #10 in its 2015 Gartner Supply Chain Top 25: Europe Top 15.

Schneider Electric joins the top 15 for the first time this year, jumping 12 spots from its 2014 ranking.

Gartner identified the top 15 performers in the report based on a combination of financial metrics (revenue growth, Return On Assets [ROA] and inventory), and a composite score that consists of the opinion of peers, Gartner supply chain analysts.

"When assessing the supply chain rankings for 2015, we identified some common practices and challenges experienced by leading supply chain organizations in Europe," said Stan Aronow, Research Vice President at Gartner.

A willingness to invest in, and experiment with, technology and digital business models has given the top companies an edge in terms of collaboration, enhanced segmentation and local responsiveness.

"Our goal is to ensure that our large base of global customers experience the benefits of our tailored supply chain approach," said Annette Clayton, Executive Vice President, Global Supply Chain, Schneider Electric.

"We believe Gartner's European Supply Chain rating confirms our position in the market and our commitment to providing customers with a best-in-class supply chain that meets their unique challenges."

Markit Opportunity crowned Barclays Africa Supply Chain Champion

Barclays Africa Group Limited (Barclays Africa) crowned Markit Opportunity the Barclays Africa Supply Chain Challenge champion at a panel submission judging event held at The Bandwidth Barn Accelerator in Cape Town recently.

Winners with the judges

The pan-African challenge, under the Rise in Africa umbrella, which launched in July, invited teams of innovators to submit ideas to redefine the supply chain process and enable economic growth across Africa.

Represented by their CEO and Founder Ashley King-Bischof, Markit Opportunity, from Kenya, triumphed over four other innovative finalists, by demonstrating a scalable solution to improve incomes of smallholder farmers.

Markit Opportunity incentivises regional trade by leveraging mobile technology and logistics to create trusted, transparent and efficient supply chains. The company provides a mobile platform that connects traders in urban markets to farmers with real-time supply and demand statistics, as well as market related pricing.

The judging panel of industry experts including Erik Hersman, CEO of BRCK, Teju Ajani, regional content partnerships lead for YouTube and Ian Merrington, CEO of the Cape Innovation and Technology Initiative vigorously engaged the five finalists as they presented their concepts.

"When it came to selection process, the very high calibre of submissions provided some testing conversations for the judging panel. Today's finalists are a great reflection of the rich vein of innovation emanating from the African continent," says Ashley Veasey, CIO, Barclays Africa and judging panel member.

Markit Opportunity will receive $10 000 in support of their venture.

Unprecedented long-term guarantee for batteries in load shedding applications

The prevalence of routine load shedding and power outages across the African continent including South Africa has exposed one of the Achilles heels of standby power devices such as Uninterruptible Power Supply (UPS) and inverter-based systems. This is the shortened lifespan of regular lead-acid batteries (including deep-cycle batteries) when subjected to full depletion on a regular basis.

"These systems are not designed to cope with load-shedding," says Jack Ward, MD of power provisioning specialist Powermode. *"They are intended to backup sensitive equipment such as computers, medical and telecommunications equipment for brief periods of time – between five and 15 minutes. During this time diesel generators take over or operators are expected to save open files and execute a safe power-down.*

"A period of load shedding, usually ranging from two to four hours, can fully deplete a battery pack. If repeated often enough, the batteries' life can be severely compromised – reduced to around six months or less in many cases."

Ward claims that today, battery manufacturers seldom stand by their stated warranties, often claiming abuse in load shedding applications as an 'out'.

Against this backdrop, Powermode has launched the Q-on LR (Long Run) Battery Pack which features a 'first' for the SA market in the form of a comprehensive three-year guarantee (over and above the manufacturer's warranty). The integrated battery pack comprises a number of sealed deep cycle VRLA (Valve Regulated Lead Acid) Absorbed Glass Matt batteries.

Jack Ward
MD | Powermode

"Underpinning Powermode's money-back guarantee is the 'smart' technology built into the battery pack which is sized according to load," explains Ward. *"This includes a battery charger with a computerised battery balancing harness that automatically reports - via the Internet and a 'cloud-based' portal to the Powermode control room - on a wide range of parameters associated with individual batteries in the pack.*

"Here we monitor data streams containing information critical to the well-being of individual batteries, including temperature, state of charge and depth of discharge. We keep a tally of the number of discharge/charge cycles."

Ward emphasises that Powermode will provide real-time management and regular servicing of a Q-on LR Battery Pack, no matter where it is sited country-wide.

Ward adds that the Q-on LR Battery Pack, which is housed in a purpose-built cabinet, is an ideal complement to power standby units in retail and other applications where the use of generators is impossible or prohibited.

Innes House Museum of Electrical Engineering

André Hoffmann (SAIEE President) officially opened the SAIEE Museum by cutting the ribbon on the steps of the Herbert Baker-designed Innes House

A few guests in attendance at the opening of the museum.

From left Richard Dismore (Radio Specialist), André Hoffmann and Max Clarke (Chairman, Historical Section)

The Innes House Museum was officially opened by SAIEE President André Hoffman on Friday afternoon 6th November, 2015, when he symbolically cut a ribbon across the entrance steps and opened the main door of the building. This took place at the conclusion of the regular monthly meeting of the Institute's Council and in his address to the gathering he thanked all involved in this important project.

He pointed out that it has been a long road to reach this milestone and many people have been involved, starting with a small group of engineers at the CSIR in November 1978 who discussed the possibility of ".. the collection of historical data and items for a future museum of electrical engineering equipment...." and effectively planted the seed which has now blossomed into life.

The baton was taken up six months later when SAIEE members G J Korvink; H T Aspinal and V J Bakman met in Kelvin House on 23rd May 1979 and formed "The Historical Interest Group" "... to ensure the preservation of certain electrical equipment." Over the years numerous members joined the group and contributed to its workings and in August 2002, by resolution of the Council, the HIG became a full "Section" of the Institute.

Initially, items were stored in whatever facilities were available. The majority of the larger artefacts were kept in Eskom's Robinson Substation and Johannesburg Electricity's Wemmer Pan substation, but with the Institute's move to Observatory in June 1990, storage was arranged in the outbuildings of Innes House, in "spare" rooms in the AS & TS buildings on the Observatory site, and the "Second House" (sometimes referred to as the Engineer's House) also on the site.

The collection of books – many donated by the family of Prof. G D Walker , one of the early members of the HIG – were also transferred to Observatory and arranged as a library, housed in a portion of the Innes House outbuildings.

The planned development of facilities by SAASTA on the Observatory site necessitated the removal of artefacts from various rooms in the old AS & TS buildings and resulted in the hiring of a 12m "container" in January 2007, to provide temporary accommodation for artefacts, pending the building of the new SAIEE

An aerial view of the ground floor in the Museum.

Visitors watching a movie about the history of Electrical Engineering in South Africa.

offices and storage facilities. This was finally removed in June of 2011 when the new building was complete and the storeroom became available.

With the completion of renovations to Innes House in 2012, the first displays of items were placed in the museum early in 2013 and the planning and setting up of other exhibits has proceed ever since. The museum is a "living" facility and it has been accepted that it will never really be "complete" as there will always be changes of some sort in the displays.

Special guests among the gathering on Friday were Ted Hart, current President of the Antique Wireless Association (AWA), Jacque Scholtz Vice-President of the AWA and Henry Stephen VP-elect of the AWA, all of who, together with the members of the HS Committee have made significant contributions of time, talent and equipment to setting up the various displays. As part of the opening proceedings the AWA arranged a radio "hook up" with the President of the South African Radio League who gave a short congratulatory message to the President and the Institute members.

'Green' powder coating plant a first for Sub-Saharan Africa

A Cape Town based company is the first in Sub-Saharan Africa to offer an environmentally-friendly method of pre-treating architectural aluminium prior to powder coating.

Blue Willow Aluminium has built an automated processing plant in line with International Best Practice which is hexavalent chromium-free for environmentally-friendly pre-treatment manufacturing. Recognised as a human carcinogen if inhaled, hexavalent chromium is also what infamously contaminated groundwater in Hinkley, United States, leading to a lawsuit with a multi-million dollar settlement and the movie Erin Brockovich.

"We have built the first plant in Sub-Saharan Africa that fully complies with International Legislation and are proud to have created a processing plant which includes the most environmentally advanced and technically sophisticated chemical processes for preparation of architectural aluminium prior to powder-coating," said Blue Willow Aluminium GM, Schalk Pretorius of the Atlantis Industrial plant.

"Our guaranteed quality comes from the constant reproducible production standards generated by the automated system. Previously, local companies had the frustration of irregular quality with high wastage factors, and were forced to import and hold substantial stock to counter the inconsistencies of local alternatives. Blue Willow Aluminium has filled a growing need in the local market for access to world class powder coating technology, which results in aluminium of an equally high quality."

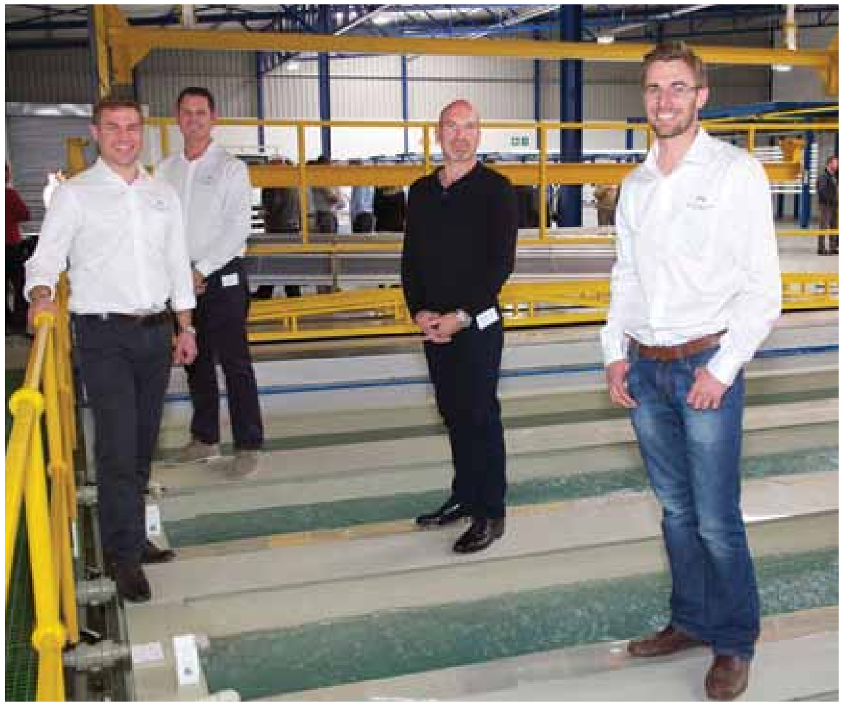
The pre-treatment process begins with the production of ultra-pure water, used throughout the process to provide a transitional medium from one chemical process to the next.

All water fed into the system is used in the process, including the reverse osmosis waste stream. Once the water has fulfilled its function through the pre-treatment process, it is automatically treated and then re-utilized in the garden irrigation system. *"The process is so advanced the recycled water is, in fact, cleaner than municipal water that goes into the pre-treatment plant,"* Pretorius said.

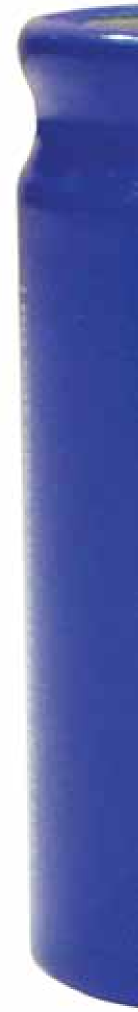
Aluminium pre-treatment is done in two chemical zones at ambient temperature. The first zone deoxidises the aluminium by removing the oxidised surface layer including all contamination contained with the surface microstructure. The second zone forms a reaction layer with the aluminium, providing galvanic protection, a layer for powder-paint to adhere and, bare corrosion protection of the aluminium while in transition after the pre-treatment step to the final powder-coating process.

The powder coating system installed at Blue Willow Aluminium is the most efficient and fastest colour change system available on the market - Nordson's most advanced system available globally.

Offering absolute and consistent process controls, the system incorporates the ColorMax Booth, the Encore HD Application equipment, powder feed pumps and the Spectrum HD powder feed centre. *"This state-of-the-art powder coating system is truly cutting edge and completes Blue Willow Aluminium's outstanding service offering."*



Schalk Pretorius (right) MD of Blue Willow Aluminium, Shawn Williams (Wet chemical process technology partner), Jean Van der Westhuizen (Technical Director) and Heinrich Primic (Sales Director).



How to Charge Supercapacitor Banks for Energy Storage

Supercapacitors (SCs), also known as ultracapacitors and electric double-layer capacitors, are finding use in a variety of power management applications.

BY | JOHN WHITE | PR ENG

In automotive applications such as start-stop systems with regenerative braking, SCs can provide the energy needed to engage the starter to restart the combustion engine as well as accept the kinetic energy recovered during braking. Supercapacitors are advantageous because they can be charged and discharged significantly more times than traditional lead-acid batteries, and can also absorb energy more rapidly without degrading their expected lifetime. These capabilities also make SCs attractive for industrial backup power supply systems, quick-recharge cordless power tools and remote sensors where the frequent replacement of batteries isn't practical.

This article addresses the challenges related to charging these large capacitors, and shows power system designers how to evaluate and select the best system configuration for backup energy storage. An SC charger solution is demonstrated, with waveforms and detailed interpretations presented.

SYSTEM ELABORATION

There are many system configurations using SC banks as backup energy storage. To get started, designers will need to target their energy storage configuration and then decide at what voltage the energy can be stored. Selecting the solution depends on the power and voltage requirements of the load and the energy and voltage capabilities of the SC. Once the best solution is identified, tradeoffs between overall performances and cost must be made.

Figure 1 shows the block diagram of a high efficiency solution where the loads are devices requiring regulated input voltages (3.3V, 5V, 12V, etc.). The main supply of 48V is supplying Switching Regulator 2 (SW2) in normal operation while simultaneously charging the SC bank to 25V through Switching Regulator 1 (SW1). When the main supply is disconnected, the SC bank then supplies SW2 to maintain load operation without interruption.

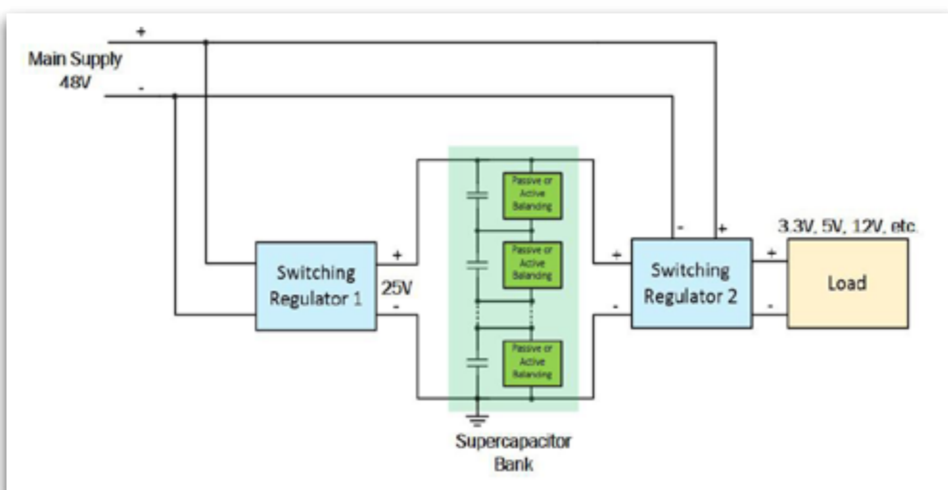


Figure 1. Block Diagram of a Battery Backup System Example using a Supercapacitor Bank

SYSTEM DESIGN AND CHALLENGES

Once an SC cell has been chosen, the system designer must select the target voltage at which each SC cell will be charged. This is done based on the rating curves of the SC. Most SC cells are rated in the range of 2.5V to 3.3V at room temp—this rating falls at higher temps and with longer desired lifetime. Typically, the target voltage should be set below the maximum rated voltage to extend the operating life of the SC.

Next, the voltage desired for the bank of SCs and SW2 topology can be chosen. The SC bank configurations can be in parallel, series or a combination of series strings in parallel. Since the cell voltage rating is typically under 3.3V and the loads often require equal or higher supplies, the options

Super Capacitor Charging...

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for cell configuration and SW2 will be to use a single cell with a boost converter or multiple cells in series and a buck or buck-boost regulator. To use a boost, we must ensure that as the SC discharges, the voltage doesn't drop below the minimum operating input voltage for SW2. This can be up to half of the charged voltage of the SC, and for this reason, we'll illustrate a bank that consists of a series combination of SCs and a simple buck regulator for SW1. Then, if energy requirements demand, multiple series strings will be placed in parallel.

If a series combination of SCs is chosen, the number of cells used must be selected based on the maximum desired voltage at the top of the string. More capacitors in series means higher voltage of the SC string with less capacitance. For instance, consider the choice of using two strings of four 2.7V 10F capacitors versus one string of eight (in series) of the same capacitor. While the same total charge and energy can be stored, the usable voltage range of the string makes the single series string advantageous. For example, to have a load requiring 5V bias, the required voltage for SW2 is around 6V, considering its maximum duty cycle and other dropout factors.

- The energy in a capacitor is $W=CV^2/2$ and the energy that can be used is $W= C/2(V_{charge}^2 - V_{dicharge}^2)$
- For two strings of four capacitors, the usable energy is $W = 2*[(10F/4)/2*((2.7V*4)^2-6V^2)] = 201.6J$
- The usable energy in the single string of eight (in series) is $W = 1*[(10F/8)/2*((2.7V*8)2-6V^2)] = 269.1J$

Since both capacitor banks store the same total energy, the string with lower voltage has a greater percentage of charge wasted/unusable. In this case, the higher string voltage is preferable to fully utilize the SCs. A third system challenge arises when considering how to charge the SC bank. Initially, when the SC voltage is 0, SW1 has to work at a condition similar to an output short for a fairly long period of time due to the high capacitance. A regular SW1 may get stuck in hiccup mode and fail to charge the SC. To protect the SC and SW1, additional current limiting function is necessary at the beginning of the charging stage. A good solution would be for SW1 to provide continuous charging current for an extended amount of time at almost no output voltage.

There are various methodologies to charge an SC. Constant current/constant voltage (CICV) is more commonly used and the preferred method as shown in Figure 2 (CICV curve). At the beginning of the charge cycle, the charging device (SW1) operates in constant current mode providing a constant current to the SC such that its voltage is linearly increasing. The SC is charged to a target voltage, at which time the constant voltage loop becomes active and accurately controls the SC charge level to be constant to avoid over charging. Again, this preferred solution places requirements on the power management functions that will need to be considered.

Referring back to Figure 1 as an example, with a main supply of 48V, an SC bank voltage of 25V and load voltages of 3.3V, 5V, 12V, etc., a synchronous buck function for both SW1 and SW2 is appropriate. With the primary challenge relating to SC charging, the choice for SW1 is critical. The ideal solution for SW1 would require power management functionality that is capable of operating with high input (48V) and output (25V) voltages while also providing CICV regulating capability.

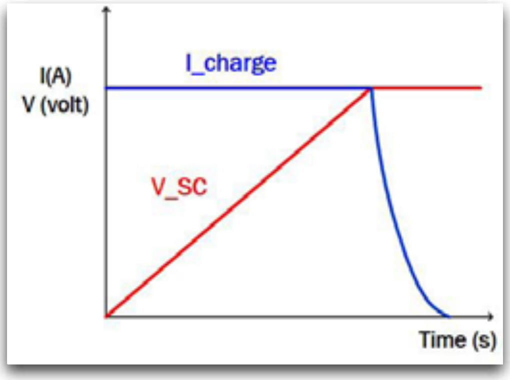

Figure 2. CICV Supercapacitor Charge Control

DEMONSTRATION OF A SUPERCAPACITOR CHARGER SOLUTION

To demonstrate the SC charging behaviour, we'll use a sync buck regulator example. We'll show the key problems and resolving techniques, and use experimental waveforms to aid our understanding.

Figure 3 shows the simplified schematic of Intersil's ISL78268 controlling a sync buck regulator that achieves CICV control. To charge a supercapacitor bank to 25V with CICV control, the following capabilities were considered when selecting the controller:

1. Synchronous buck controller that can operate with V_{IN} >= 48V and V_{OUT} >= 25V.
2. Constant current and constant voltage regulating capability with automatic transitions between regulation modes.
3. Accurate current sense inputs for the CI portion that operate over the supply voltages of the system. Referring to Figure 3, the controller is sensing the inductor's continuous current, which is the charging current. The controller's

Looks can be deceiving
AND OFTEN DEADLY

There is a very large choice of lighting products available to contractors, specifiers, distributors and users.

Many products, particularly non-decorative ones, are barely distinguishable from each other and, from appearances, it is difficult for most people to judge whether a product is safe or not.

Light fittings are subject to compulsory specifications but a number of shortcuts can be and are being taken by unscrupulous suppliers to reduce cost and offer products at seductive prices, for example:

- Sub-standard insulation that risks electrocution of installers and users
- Poor mechanical construction that compromises safety
- The use of flammable materials that present fire risk
- Careless design and assembly of cable routing and connections that risk safety

What can you do? Some guidelines:

- Be suspicious of prices substantially below the going rate for comparable product on offer
- Look for proper markings: Manufacturer's name; Lamp type and wattage; Rated supply voltage and written installation & maintenance instructions and precautions
- Look for authentication of quality: Notably protection-level markings (Class I , II or III)
- Purchase brands you can trust.
- Consult the SAFEhouse lighting guide **
- Contact the SAFEhouse Association for assistance.

** Available on our website or contact SAFEhouse

SAFEhouse members have signed a code of conduct: Your assurance of commitment to offer only safe electrical products

SAFE™ house
Suppliers you can trust

The SAFEhouse code of conduct includes:

- To offer only products that are safe
- To advise customers if any of their sold products fail this undertaking
- To recall unsafe products
- To replace unsafe products or render them safe

The SAFEhouse Association is a non-profit, industry organisation committed to the fight against sub-standard, unsafe electrical products.

For more information contact:
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www.safehousesa.co.za

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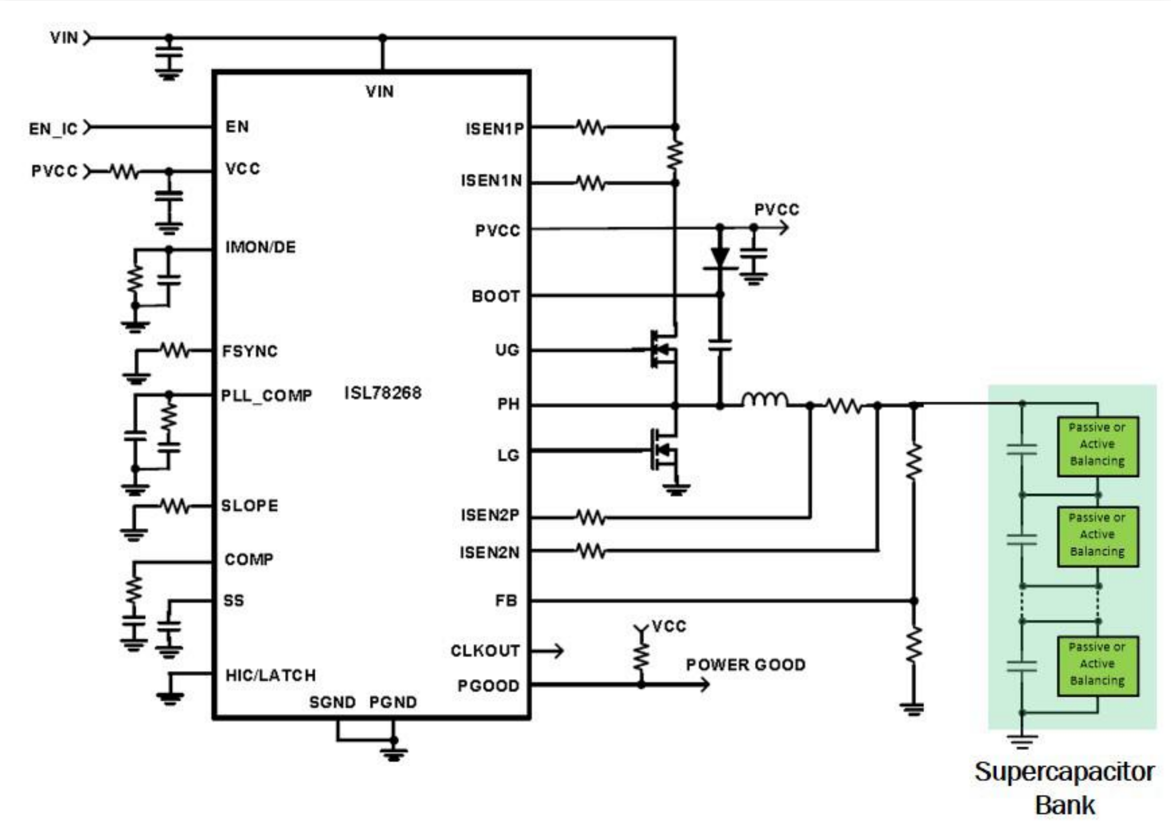

Figure 3. Simplified Schematic of a Sync Buck Regulator Achieving CICV SC Charging Control

current sense amplifier must withstand the common mode voltage, which is 25V in this case.

Figure 4 shows a small section of the ISL78268 sync buck controller's functional block diagram. As shown, there are two independent error amplifiers labeled Gm1 and Gm2, which serve to regulate constant voltage (Gm1) and constant current (Gm2).

Error amplifier Gm1 works for CV close loop control. It compares the feedback voltage at FB to the internal 1.6V reference voltage and creates an error voltage at the COMP pin. The FB pin is tied to a resistor divider from the output voltage and is set such that FB will be 1.6V when the output is at the desired voltage. The COMP voltage then represents the difference between the desired output voltage and the actual output voltage. COMP is then compared to the peak inductor ramp to generate the PWM signal to control the output voltage to be constant.

Error amplifier Gm2 works for CI close loop control. It compares IMON/DE pin voltage and the internal 1.6V reference and creates an error output at the COMP pin. The IMON/DE pin voltage is generated internally and represents the average output inductor load current. Thus, the COMP voltage when Gm2 loop is active (the diode between the output of Gm1 and Gm2 effectively selects which loop is active), represents the difference between the desired output current and the actual output current. COMP is then compared to peak inductor ramp to generate PWM signal to control the output current to be constant.

At the beginning of the charge stage before the SC voltage reaches its target, Gm2 is dominantly driving the COMP pin, causing the PWM output to achieve CI control. When the SC voltage is charged to target, the charging current is reduced causing IMON/DE pin voltage to fall low and CI loop disengages (when IMON/DE<1.6V) and the CV loop naturally takes over to control COMP thus controlling output voltage constant.

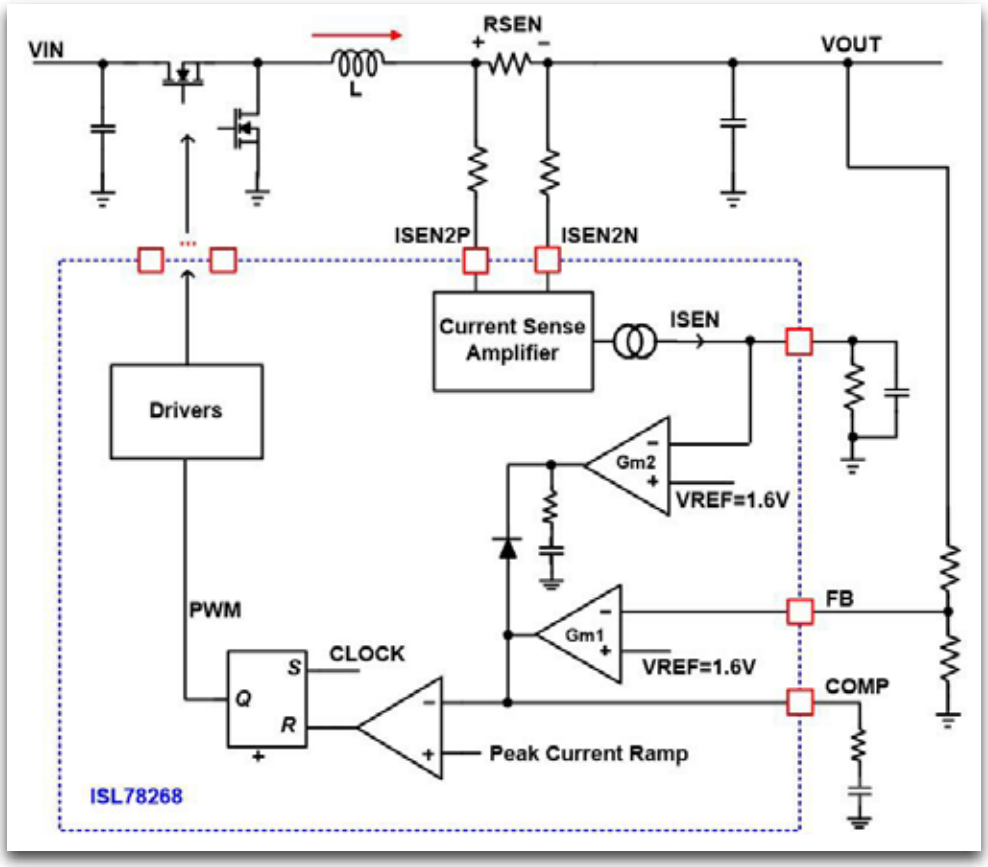

Figure 4. ISL78268 CICV Loop Simplified Block Diagram

The ISL78268 buck controller has both peak current mode control for PWM generation (reliable cycle-by-cycle peak current modulator) and outer constant average current loop ideal for SC charging.

Now we'll highlight the realized SC charging implementation. Figures 5, 6 and 7 show the experimental waveforms of the synchronous buck controlled by the ISL78268 to charge a SC bank (12 50F/2.7V SC in series). The SC will be charged to 25V from the main supply.

Figure 5 shows there are several stages for the SC charging. Initially, at stage 1, Vo is barely 0. The average current signal on the ISL78268's IMON/DE pin has not yet reached 1.6V (the reference value for the desired charging current), so the CI loop has not yet engaged. At this stage, the inductor's peak current is cycle-by-cycle limited to fixed OC threshold. At the beginning of the charging state when the VOUT is low (FB<0.4V), the switching frequency is capped at 50kHz as a precaution to overcome the mentioned inductor runaway problem for peak current limiting at low VOUT.

Figure 6 shows a zoomed in waveform of stage 1. Stage 2 starts when the IMON/DE pin voltage (yellow trace) reaches 1.6V. Here, the CI loop engages and pulls the COMP signal (cyan trace) lower, thus beginning to regulate the output current and causing the IMON/DE pin voltage to remain constant. IMON/DE pin voltage represents the sensed average output current signal. The IL waveform (green trace) shows the average current is controlled to be constant

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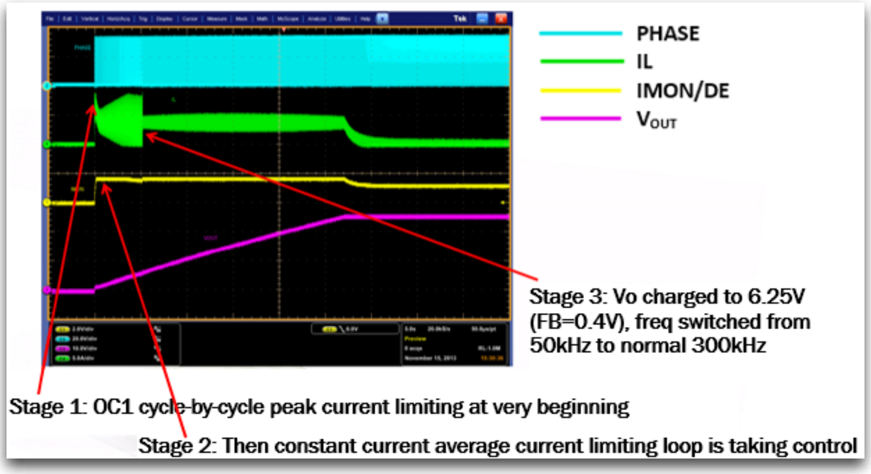

Figure 5. Bench Waveforms of SC Charging

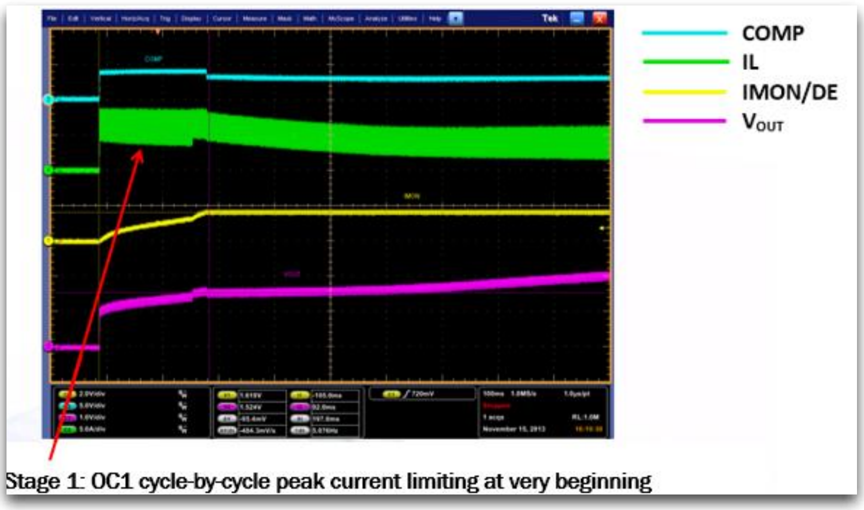

Figure 6. Zoom in Bench Waveforms of SC Charging at Stage 1

Figure 7. Bench Waveforms of SC Charging

during stage 2. The output voltage (pink trace) shows the SC is linearly charged by the constant charging current.

Stage 3 starts when the FB pin detects 0.4V (Figure 7). After detection, the constant current regulation is known to be fully engaged, so the switching frequency can be automatically adjusted to the programmed frequency of 300kHz. With higher switching frequency, the inductor current ripple (green trace) is significantly reduced. The output voltage (pink trace) continues to linearly increase, indicating the SC is being linearly charged.

Referring back to Figure 5, stage 3 proceeds until Vo reaches the target voltage of 25V. Once that occurs, the CV loop engages and regulates the output voltage. The average current loop disengages. Figure 5 shows that the output voltage (pink trace) levels off and the inductor current drops low. The IMON/DE pin, representing the average charging current also falls, signifying the end to constant current regulation.

CONCLUSION

Supercapacitors are adopted as energy storage solutions in certain automotive, industrial and consumer products due to their intrinsic physical characteristics that provide advantages over traditional batteries. To maximize the energy stored in the SC bank, it's often best to stack several SC cells in series to realize high bank voltages. When charging, it is preferable to use a CICV charging methodology to limit the high currents that would otherwise flow due to the low ESR of the SC if charging to a constant voltage. The constant current makes charging losses controllable within the SC, which can reduce heat generation and extend the life of the SC. Thus, it is advantageous for the charging circuits to tolerate high voltages and provide CICV regulation capability. wn

DEVELOPMENT OF MECHATRONICS AND SOFTWARE NEED TO BE CLOSELY INTEGRATED

Systems Engineering

BY | MATT COHEN | GLOBAL SERVICES AND PARTNERS

To tune a car's performance these days, you no longer need to be a traditional mechanic, but rather a software engineer. Horsepower is not determined only by the engines mechanical characteristics, but also on the software controlling it. With different control algorithms, the same engine can provide different ranges of horsepower. Andre Radon, Vice President Product Lifecycle Management at tier 1 automotive supplier Continental Automotive recently explained to attendees at an International Conference in Las Vegas, that a key differentiator between a car of 300 and 400 hp is the software. Cars are increasingly becoming computers – with millions of lines of software – on wheels. Some luxury vehicles are now home to more lines of software code than a complex IT solution. The software not only controls the complex infotainment applications, but also works together with mechanical and

Products from automobiles to mobile phones contain an increasing amount of software providing various functionality, including the control of mechatronic systems. In order to ensure optimal design in these Embedded Systems, the development of mechatronics and software need to be integrated more closely across all phases of the product lifecycle. The integration of tools to control the software lifecycle within the PLM environment is a crucial prerequisite in this context. Continental Automotive provides a Best-Practice example for the successful realization of such an integration.

electronic system components to control basic functions which affect driving behaviour and safety. This sets very high standards in terms of the quality and reliability of the embedded programs, as any bugs could be life-threatening.

According to estimates, software contributes between 60 and 80 percent of the innovations in a car. The contribution of Embedded Systems to innovations in the automotive industry is even higher. However, at the same time software has also become one of the biggest potential sources of problems. Embedded systems are hardware and software components integrated into a more comprehensive solution in order to fulfil product-specific functionalities. The end users either see nothing of the software or they only get to see the user interface without being able to influence the actual behaviour of the system.

These days, Embedded systems are not only found in cars and aircraft, but also in industrial plants, automation technology, in medical devices and in environmental and energy technology. Many economies worldwide are significantly influenced by embedded systems development. Research suggests that the US, Japan, and Germany are at the top of this market. Embedded systems allow faster reactions to new market requirements, more cost-

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effective implementation of innovations to make market-ready products and stronger differentiation of these products in terms of functionality without having to alter the hardware (e.g. mechanics and electronics). The rise of embedded systems has led to a steadily increasing value contribution of electric and electronic components to motor vehicles. Over 50 percent of the costs of new systems stem from embedded software. This shifts the importance of various professional groups in automotive development – traditional mechanical developers are increasingly being dominated by system and software developers. At Continental Automotive, for example, two thirds of the engineers now work in systems and software engineering. According to Radon, Continental Automotive has more software programmers than many leading IT companies.

DYNAMIC CHANGE PROCESS

The development of Embedded Systems is a complex process involving a broad range specialized engineering disciplines which use different systems, have different processes, and communicate in different technical language. So, traditionally, mechatronics and software components are developed separately and in parallel to one another. They are only brought together at a relatively late point in the development process. This has several disadvantages including significant risk that the software and hardware do not function properly together, creating expensive rework. At the same time, it makes multi-disciplinary optimization more difficult, where the aim is to optimise the functionality of the system as a whole, possibly taking into consideration less than optimum results from individual system components.

When challenges do arise, in many cases, the software developers can solve the problem more quickly and easily than the mechanics developers. After all, it is not only much faster to change software, it is also a lot more cost-effective than altering mechanical components. At Continental Automotive, for example, there is an average of 100 software changes and around ten electronics alterations for every hardware change. However, it is this dynamic of software development which needs to be controlled and coordinated for the development of Embedded Systems. Unlike pure software applications, Embedded systems require close interaction between software, electronics and hardware, which means that a software change which is not controlled and coordinated can lead to a complete breakdown or major functionality issue for the whole system. It is no coincidence that some 50 percent of guarantee costs go towards Embedded Systems these days.

Source: Tech-Clarity 2011

When analysing error causes and potential efficiency improvements in embedded systems, quality assurance across system boundaries turns out to be the biggest potential for optimization. In order to guarantee high levels of quality, it is necessary to produce an integral overview of the system to be developed and all its configurations and variants as early as possible and continue to maintain it on a consistent basis. The approach to application must be holistic and system-oriented in order to ascertain the influence that the software has on the hardware and vice versa at any stage.

INTEGRATED DEVELOPMENT APPROACH

The central challenge during the development of Embedded Systems is process integration. This begins with requirements management, which is the capturing and representation of functional (and non-functional) requirements at the system level. The individual system components (e.g., hardware, electronics, software, etc.) and the relations among each other need to be reflected in an integral architecture strategy.

By doing so interdependencies can be recognized and the impact of changes can be evaluated. Accordingly, a model based development process facilitates the virtual validation of the Embedded Systems. Early analysis and validation of Embedded Systems require comprehensive configuration management and a powerful management of versions. Such configuration management also needs to reflect the different dynamics of changes that occur during the development of software as opposed to the development of mechatronics. Product configurations from software, electronics and mechanics with their different life cycles must be traceable throughout the design and development processes in order to avoid product liability issues and to ensure a high level of product quality.

Interdisciplinary lifecycle management for mechatronics and embedded systems, is a prerequisite for process integration. An integral product development platform should be able to:

- Document complete product configurations, its variants and its dynamics of change so that they can be traced at early stage;
- Provide a virtual overall model for reference and validation at all phases of the life cycle;
- Represent interdependencies between requirements, functions, product and tests in different views and synchronize them in case of changes; and
- Incorporate individual tools of engineering disciplines involved and support their specific requirements for the process.

In analogy to the V-Model approach of software development, the system is first considered on an integral basis across all disciplines.

It is then broken down into system components and working packages for different disciplines, which are implemented and finally integrated back again.

Discipline-related activities are still being processed separately, but they are held together in structured form by a shared system configuration layer.

The goal of such a procedure is to carry out tests at a system level within the process as early and reliably as possible. wn

Earn CPD Credits

Mechatronics at the forefront of innovation

As competition has intensified and market windows have shortened, mechatronic technologies have become critical to success. Indeed, yesterday's mechatronic innovations are today's commodities.

Even as mechatronics have become more prevalent, most manufacturers lack expertise across all mechatronics disciplines including software, electronics and mechanical engineering. As a result, companies rely on partners to provide key elements in their products. This further complicates the primary challenge of mechatronic product development: integrating these disciplines into a coherent, synchronized product lifecycle.

According to Aberdeen Group, 68 percent of manufacturers cite synchronization of mechanical and electrical design representations as a key product development challenge. Forty-seven percent lack expertise in systems design or specific mechatronic disciplines. Yet, to be best-in-class, manufacturers must engage in a process of continual mechatronic innovation.

This same study found that manufacturers that are best-in-class in mechatronics product development

BY | BOB FLORY | MSME | BSME

Innovative manufacturers across all industries have increasingly incorporated electronics and software into their mechanical products in order to deliver features that customers want at a competitive price.

hit their revenue, cost, launch date and quality targets 84 percent of the time. Four out of five of these companies address mechatronic integration issues early in the design process.

Other important trends are affecting manufacturers' ability to optimise processes across the mechatronic product lifecycle:

- The development and manufacture of electronics components is increasingly outsourced to suppliers and strategic partners, increasing the challenge of coordinating development and Protecting Intellectual property (IP);
- Higher warranty issues can result from more complex products;
- Security, configuration management and change management present significant challenges;
- Complex mechatronic products increase the need for change control, version control and traceability.

In order to compete, manufacturers need to be able to synchronize all aspects of complex product and process design, pushing all systems engineering and design issues to the front of the process whenever possible. They must optimise product performance, integration and quality by unifying interdependent mechanical, electrical and software subsystems – many of which may be designed and built by suppliers. According to Dr. M. K. Ramasubramanian, Associate Professor at North Carolina State's Department of Mechanical and Aerospace, this requires "the synergistic integration of precision

Mechatronics at the forefront of innovation

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mechanical engineering, electronic control and systems thinking in the design of intelligent products and processes."

Product Life-cycle Management (PLM) solutions can provide an ideal framework for implementing enterprise-wide mechatronics goals. When applied strategically, PLM technologies using Extensible Markup Language (XML) and open system standards can create a digital environment that supports secured access and exchange of data among the multitude of applications that optimise and analyse the product and process functions in each of the disciplines and across all stages of the product lifecycle.

This paper discusses focus areas that need to be addressed if manufacturers want to create a highly efficient product development and manufacturing environment that fosters continuous and measurable mechatronic innovation:

- Systems engineering and requirements management;
- Establish a framework to architect the mechatronic system, then create and communicate the system requirements to downstream decision makers;
- Development management;
- Develop and synchronize all the designs, components and interfaces that comprise a mechatronics product in a whole system context;
- Production management;
- Plan and develop the manufacturing processes for harnesses, printed circuit boards and software to track system configurations and quality;
- Service and diagnostics management;
- Create a closed loop environment that ensures continuous improvement;
- Systems engineering and requirements management.

To respond to the challenges posed by mechatronic products, companies need to support new business practices that transcend disciplines and transform product development, manufacturing and support. They must address the complex integration issues that are driving up costs late in the design cycle and at all stages of the product lifecycle.

These issues are amplified when manufacturers work with partners and suppliers that provide needed expertise in electronics or software development. While this increases collective knowledge, it also adds complexity, as companies need to coordinate all stages of the lifecycle not only with other companies but also among multiple domains within each company.

To succeed, manufacturers need to implement a broad set of processes and methods for modelling and analysing interactions among the requirements, subsystems, constraints and components that make up a mechatronics product. This requires a high degree of synchronization, optimization and cross-disciplinary management that is only possible through a systems engineering approach to managing the entire product lifecycle.

Systems engineering principles are fundamental to mechatronics product development. A systems engineering approach facilitates collaboration among multiple departments and disciplines – not simply within the enterprise but also among suppliers and strategic partners across the value chain.

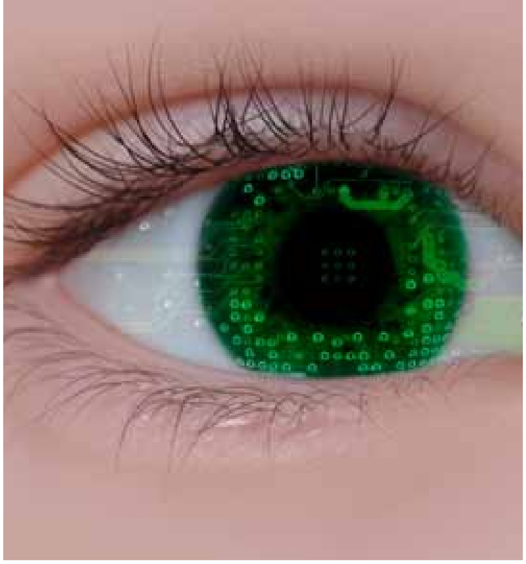
MECHATRONIC PRODUCT DEVELOPMENT CHALLENGES

When supported by enterprise PLM, systems engineering provides a holistic view of design, manufacturing and support that manages the complexity of dealing with multiple disciplines, design and manufacturing groups spread across the globe. It provides the ability to define, manage, control and synchronize all of the features and functions that comprise a mechatronics product, and to ensure they all interface seamlessly.

The various mechanical, electronic and software components that make up the final product must be aligned and evaluated as a whole in order to develop the optimal system architecture that meets performance and design requirements. All physical and functional subsystems and parts must work together as specified, and maintenance schedules have to be mapped out well in advance.

By subscribing to these criteria, subsystems can be designed to meet the needs of the overall product. Product-wide changes can be made in the system architecture by changing key product parameters such as the wing angle of an aeroplane or the table size, height and capacity of a machine tool. These changes can then be communicated through a formal change control and notification process. Along with the overall strength in large assembly modelling and inter-part modelling, digital product development is able to support the construction of complex, re-usable product assemblies.

Designing products from the top down and independent of geometry accelerates the initial stages of product planning using information from prior designs. Systems-based modelling streamlines the initiation of new products by linking simplified conceptual models to the control structure. Changing product parameters




PERFORMANCE
OPERATIONS
EFFICIENCY
PROJECT
ADVICE
CONSULTING
PROCESS
ORGANIZATION
STRATEGY

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in the control structure and propagating the changes through to the conceptual design allows users to quickly investigate design alternatives.

PLM solutions facilitate the development of mechatronic products by providing capabilities that can model and analyse interactions among the requirements, subsystems, constraints and components of complex products that can include mechanical, electrical and software elements. PLM enables engineers to rapidly model and evaluate design alternatives to ensure that products are right the first time. Real-time decision making takes place in the context of the initial design intent as well as real-world experience on the factory floor. Traceability is supported throughout the life of the product.

PLM provides a robust data management environment that enables companies to manage mechanical, software, electronic and electrical components both as individual elements of a product and as an integrated whole. By including electronics and embedded software in revision control, engineering workflows, change management and configuration management, the right data management solution can help companies optimise processes across multiple design and manufacturing disciplines throughout the product's life.

Essential steps for optimising mechatronic product development

- Resolve design and integration issues as early as possible in the product development process by harmonizing mechanical, electrical, software engineering systems
- Improve collaboration by more tightly coordinating activities with strategic partners across multiple domains and disciplines
- Communicate complex product requirements among teams in suppliers and OEMs with as much system and engineering context as possible
- Provide all disciplines with ready access to synchronized product data
- Bridge separate IT environments for each engineering discipline

REQUIREMENTS MANAGEMENT

Early in the mechatronics development cycle, companies need to focus on defining customer needs and the functionality required for each product component or subsystem. Requirements are documented and preliminary designs are shared in a design synthesis process. Products and systems are then validated and modelled within the context of the whole product.

Systems engineering integrates all the disciplines and speciality groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets user needs.

At the same time, market requirements must be supplemented with quantifiable constraints that determine the success of take-to-market programs in terms of their cost and delivery schedules, as well as their ability to satisfy established performance, ergonomic, safety, usability, reliability, maintainability, recycling/disposal and other compliance-related metric.

Companies must leverage systems engineering to model and analyse the interactions among a product's requirements, subsystems, constraints and components and to optimise the trade-offs that drive crucial decisions across the entire product life cycle. The result of this systems architecting process is a correct set of product requirements that must be managed and closely integrated within and across disciplines to effectively feed product engineering and manufacturing.

Within an optimised mechatronics requirements management environment, product teams across multiple disciplines understand their decisions in the context of the whole system's market, regulatory and design requirements and relate these requirements to fine-grain design elements and performance targets that can

be tracked and updated throughout the product lifecycle. This should include managing all relevant designs and variants, product specifications, models (including 3D simulations) and test results.

With this in place, requirements can directly influence the processes that cross-discipline teams employ when making and executing design decisions. Design teams also can build regulatory requirements – such as end-of-life recycling regulations or hazardous waste treatment and recovery practices – into the product lifecycle and thereby turn design-for-compliance into an implemented reality.

Companies need PLM systems in place that can effectively support mechatronics requirements management. These systems must have the capability to manage change across multiple disciplines in real time. The best of these systems feature multi-discipline traceability capabilities to ensure proper document parsing and assembly. Such features can be used to create compliance documentation for the whole product across its lifecycle.

DEVELOPMENT MANAGEMENT

Mechatronics has become increasingly prevalent for the simple reason that developing new software is often much less expensive than providing the same feature in a mechanical form. Products will continue to evolve from simple mechanical systems to complex networks containing distributed computer nodes designed to deliver added features or value. If an assembly can be replaced with a software component, everything else being equal, the manufacturer is likely to opt to change the software component. In addition, software is easy to change and highly flexible.

The development of mechatronics products requires that companies excel not only in specific disciplines, but also in coordinating development efforts across disciplines and across organisational boundaries.

Manufacturers that are successful, however, can boost their innovation capacity through the integration of software that creates more distinctive products and enables product line extensions that directly lead to new revenue opportunities. They also can streamline costs by reducing the number of mechanical configurations that need to be supported as software takes over more of a product's mechanical characteristics.

PRODUCT DEVELOPMENT

Mechanical, electrical and software engineers have distinctly different design processes, organizations and technology. In the past, the very different product elements created by these diverse groups were integrated through a series of physical prototypes, a costly and time-consuming process of trial and error.

By contrast, a systems-level approach to mechatronic product development provides all contributors across the product lifecycle with an understanding of the product as a whole.

It enables them to use that total product understanding to better optimise the trade-offs that drive detailed design, manufacturing, sourcing, sales and service decisions throughout the product lifecycle.

This integrated, iterative design process ultimately produces a structure, linking requirements to system and subsystem structures and to product structure.

Mechatronics at the forefront of innovation

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This mapping of product and technology is a key to success as, when done correctly, it directly links high level product strategy to detailed development execution.

Mechatronic products require companies to coordinate development within and across disciplines. For example, the increasing requirement for sophisticated control systems in products across a wide range of industries has created an explosion in the number of Electrical Control Units (ECUs) needed to produce innovative new products. Indeed, the printed circuit board has significantly changed new product design. While often outsourced to third parties, the design of Printed Circuit Boards (PCBs) remains a critical part of the process. Today, from the initial inception, to creation, to analysis, to manufacturing, companies need a comprehensive solution for PCB design and manufacturing that includes visualization tools that provide quick diagnostics and error tracking.

Any change in the product may affect PCB requirements, such as power requirements or components chosen as well as the binary code specified by a second subsystem supplier. Software loaded on multiple control units in the system needs to be compatible, manufacturing needs to know which configurations work and if there is a field problem, the maintenance team needs to know about the as-built configuration to provide optimal support.

Similarly, companies need to synchronize the overall product development process with software source code, calibration and configuration parameters, build processes, and test structures as well as binary lifecycles governing embedded systems. Improved software lifecycle management enables companies to more accurately predict functional performance and to evaluate multiple product design alternatives more efficiently.

In the process, companies can gain important design insights and make smarter engineering decisions earlier in the design process – leading to the creation of high performance, high quality and more innovative products while reducing total product costs.

In many industries such as aerospace and defence, automotive and machinery, the harness life cycle remains a critical process. A growing number of safety issues are driving the need for redundant systems that require early validation and analysis. This may include space allocation, power consumption analysis, network bandwidth and latency.

Effective harness life cycle management requires improved integration among ECAD, MCAD and software applications to ensure synchronization of the product development effort, thereby speeding product development time and enhancing engineering productivity.

As design complexity increases, wire content grows as fast as software content. New communication buses are continually being added and power consumption is pushing the limits. To deal with these issues, a complete view of harness design is needed in order to address space allocation early in the process. The early space allocation enables companies to re-use existing components from proven designs. The early space allocation also provides the link between the 2D and 3D design aspect. This iterative process is intermixed with circuit analysis.

PLM solutions with embedded software management capabilities can provide a synchronized view of software and electromechanical parts across the

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lifecycle. This view is based on the same packaging criteria that enable companies to significantly reduce design iterations resulting from versioning errors. Companies can pre-validate virtually everything well before the product reaches the make/deliver stage. With better control of the mechatronic product development process, companies can lower their expenses associated with regulatory compliance and reduce the need for costly and complex after-sale product software service updates. The improved product quality and cost reductions can translate into higher revenues and increased profit.

PROCESS DEVELOPMENT

The process of incorporating electronics and software into traditional mechanical products is fraught with peril. Change in any one component may have ramifications across all other product components and systems. Consider the communication required to coordinate a length change of a wire in a harness, designed by a subsystem supplier. The change can affect a PCB's power requirements or the binary code specified by a second subsystem supplier. Software loaded on multiple control units in the system needs to be compatible. Manufacturing needs to know which configurations work and if there is a field problem. And the maintenance team needs to know about the as-built configuration to provide optimal support.

One of the greatest challenges of increased complexity is to determine whether to manufacture a unique harness for each product delivered or to trade-off manufacturing efficiency and extra content. Manufacturing needs to be validated as early as possible. Form board tools provide the manufacturing view of the product so that companies can quickly build tools and jigs around the harness.

Failure to fully communicate the ramifications of change can have serious consequences. If a mechanical engineer fails to tell the appropriate engineer in electronics or software about the latest change, the electrical or software engineer might have conflicting requirements. In this case, each discipline's bill of material might be out of synch. Worst of all, all of the engineers involved might think that these issues are someone else's problem and therefore fail to take corrective action.

SIMULATION AND VALIDATION

Despite the steady advance of manufacturing automation, today few manufacturing companies have adequate tools to support the sophisticated levels of manufacturing testing and validation required for mechatronics products. Most business support systems offer basic milestone lists and little more. Few testing and validation tools are connected to overall workflow, let alone to detailed design and manufacturing systems.

While simulation and validation might be optimised within specific development and process domains, today's mechatronic products require an integrated simulation model that can validate the whole product against requirements. Simulation models must connect with product functions as well as features so that manufacturers can validate that the whole product works as planned.

Ideally, every phase of the product life cycle – from conception through ongoing maintenance – should be tested and pre-validated. Wherever possible the process should be mapped to, and part of, the wider product development process. The impact of design changes must be anticipated and, when appropriate, existing processes and machining operations should be re-used and applied to new products. Gathering all manufacturing processes together in a single systems engineering environment provides the framework – an integrated "product platform" – for continuous improvement.

PLM technologies enable companies to establish an integrated simulation environment for mechatronics products by providing a digital manufacturing framework that supports virtual prototyping, including interface prototyping, to ensure first time quality for the whole product. With PLM, companies are able to pre-validate product configurations and eliminate physical prototypes with highly reliable virtual prototypes.

An integrated simulation environment can be leveraged for hardware and software-in-the-loop testing. This hybrid testing environment supports the validation of new concepts and innovations within existing architectures.

Through PLM, companies also gain the ability to trace requirements to the system design and to physical components not only to virtually test the impact of changes made in any one area on other domains, but also to ensure that any change is reflected across domains.

This enables early identification of problems in specific product configurations as well as validation of electrical design and architecture and helping teams to better quarantine issues and manage risk.

In addition, PLM enables companies to bring entire product histories along the process, moving from view to view in a logical schematic or in 3D model mode. Functions can be represented physically in views that are relevant to individual users.

When building complex products containing multiple subsystems, companies must be able to validate the manufacturing feasibility of products from the very beginning of the process, with the assurance that each “system” can be made and delivered on time and on spec. To do this, they must synchronize product manufacturing and sourcing processes with the rest of product development to ensure flawless product launches and smooth ramp-up. This requires a systems engineering environment to ensure that products are built and delivered according to plan.

As a result, companies are able to optimise product performance, integration, quality and reliability through the visual analysis of interdependent mechanical, electrical and software subsystems, constraints and components.

PRODUCTION MANAGEMENT

Discrete development activities need to come together at the right time in order to avoid delays on the factory floor. The proper timing for the introduction of each component into the production process must be well understood, as changes to existing processes will need to be made.

Upfront assurance that the product can be manufactured and sourced is essential. Before companies even think about the make/deliver process, they must evaluate that they have at their disposal the appropriate assets and resources across the value chain. Prior to manufacturing, part or component manufacturing, assembly

Mechatronics at the forefront of innovation

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planning, plant design and production management need to be thoroughly assessed and outlined in detail. Design and production alternatives with accurate cost forecasts should also be part of the plan. Companies must be able to simulate manufacturing and production processes to ensure high quality and smooth flow.

Process validation is also important for product variants. Here existing manufacturing operations, processes and plants are re-applied to product derivatives. To ensure that the older processes are able to work on new designs, a high degree of dynamic validation is required, applied as automatically as possible in the process.

PLM provides a digital manufacturing environment that supports not only the early validation of manufacturing and the impact of change on work flows. It also enables companies to evaluate various manufacturing scenarios prior to any commitment to hard tooling. Advanced PLM solutions that support mechatronics give companies the tools to manage and synchronize the manufacture of various components that need to come together for the whole system, including such capabilities as PCB assembly and test, box build and embedded software management.

More importantly, an enterprise PLM environment based on a scalable, open architecture enables manufacturers to interact with their suppliers' databases and process management systems and capture updates on their production schedules, quality results and order status. As a result, manufacturers are better able to plan their own production schedules.

Finally, PLM captures as-built data from the factory floor and makes it available upstream to inform future systems architecting, design engineering and manufacturing engineering decisions. This capability enables companies to trace the root causes of noncompliant or failed components. It provides a feedback loop that is fundamental to improved service and maintenance, reducing warranty and repair costs and facilitating validation of regulatory requirements.

SERVICE AND DIAGNOSTICS MANAGEMENT

In today's competitive environment, customer service remains an essential element of customer retention. When a customer experiences a problem, it is important to be able to fix it on the first service call. As products become increasingly complex, this becomes more difficult than ever. Repair and warranty costs can cut into the bottom line.

For example, the harness must be supported from a service standpoint. Diagnosing problems in a harness today is extremely difficult as the wires are covered with overstock and taped. Consequently, identifying the true path of the route is difficult. Harness visualization tools enable the wire harness to be seen wire by wire, facilitating quick traceability and analysis of potential failures as they are identified. A comprehensive service strategy that leverages mechatronics uses software diagnostics to pro-actively identify potential failures and to alert both the company and its customers. When this approach is not feasible, a development and manufacturing environment built on PLM can provide complete information about the product, its current state and the configuration of hardware and software. Feedback from the field can be used to investigate the root cause of performance problems and pinpoint those elements that need to be revised.

In addition, change management issues extend beyond product delivery. Software changes might occur after a product has been shipped – indeed, this is one of the advantages of mechatronics products. These changes must be tracked for future in-field updates and for feedback to product designers. Mechatronic solutions must be able to manage the changes made to each asset based on its configuration and usage patterns.

CONCLUSION

In order to compete in today's dynamic global markets, manufacturers in a variety of industries – including automotive, aerospace, defence, high tech, industrial machinery, medical instruments and consumer products – increasingly incorporate mechatronics into their products. According to research by Aberdeen Group, 40 percent of the best-in-class incorporate electronics and software into every one of their products.

To be best-in-class, manufacturers must engage in continual mechatronic innovation. This requires companies to transform their approach to systems design, development, manufacture and support. They must synchronize all aspects of the product life cycle and provide a digital environment through which discrete disciplines involved in mechatronic product development and manufacture can collaborate and communicate in real time.

Mechatronics has greatly contributed to the complexity of designing, manufacturing, delivering and supporting innovative products. In many cases, the development of electronics and embedded software exceeds that of mechanical components. To fully address the challenges presented by mechatronic products, companies need to implement data management solutions that effectively manage the software, electrical and mechanical components of products and their related manufacturing parameters in tight synchronization.

A scalable, enterprise-grade PLM solution built on an open architecture provides the capability to integrate discipline-specific applications, data and processes into a unified whole. It enables companies to effectively manage the broad set of processes and methods required to model and analyse interactions among the requirements, subsystems, constraints and components that make up today's complex products.

As a result, companies improve each contributor's understanding of the product as a whole. This total product understanding can then be used to better optimise the trade-offs that drive detailed design, manufacturing, sourcing, sales and service decisions throughout the product lifecycle. To accelerate the process and ensure demand-driven innovation, leading companies must create a real-time, global, collaborative environment that spans organisational boundaries. With PLM, companies can lower costs associated with integration issues that arise late in the design cycle, causing production delays and delaying product launch. PLM enables manufacturers to realize higher revenues and increased profit through improved product quality and reduced costs.

An integrated approach enables companies to effectively address the key areas discussed in this paper:

- Systems engineering and requirements management
- Development management
- Production management
- Service and diagnostics management wn

Earn CPD Credits

From Kettles to Supercritical

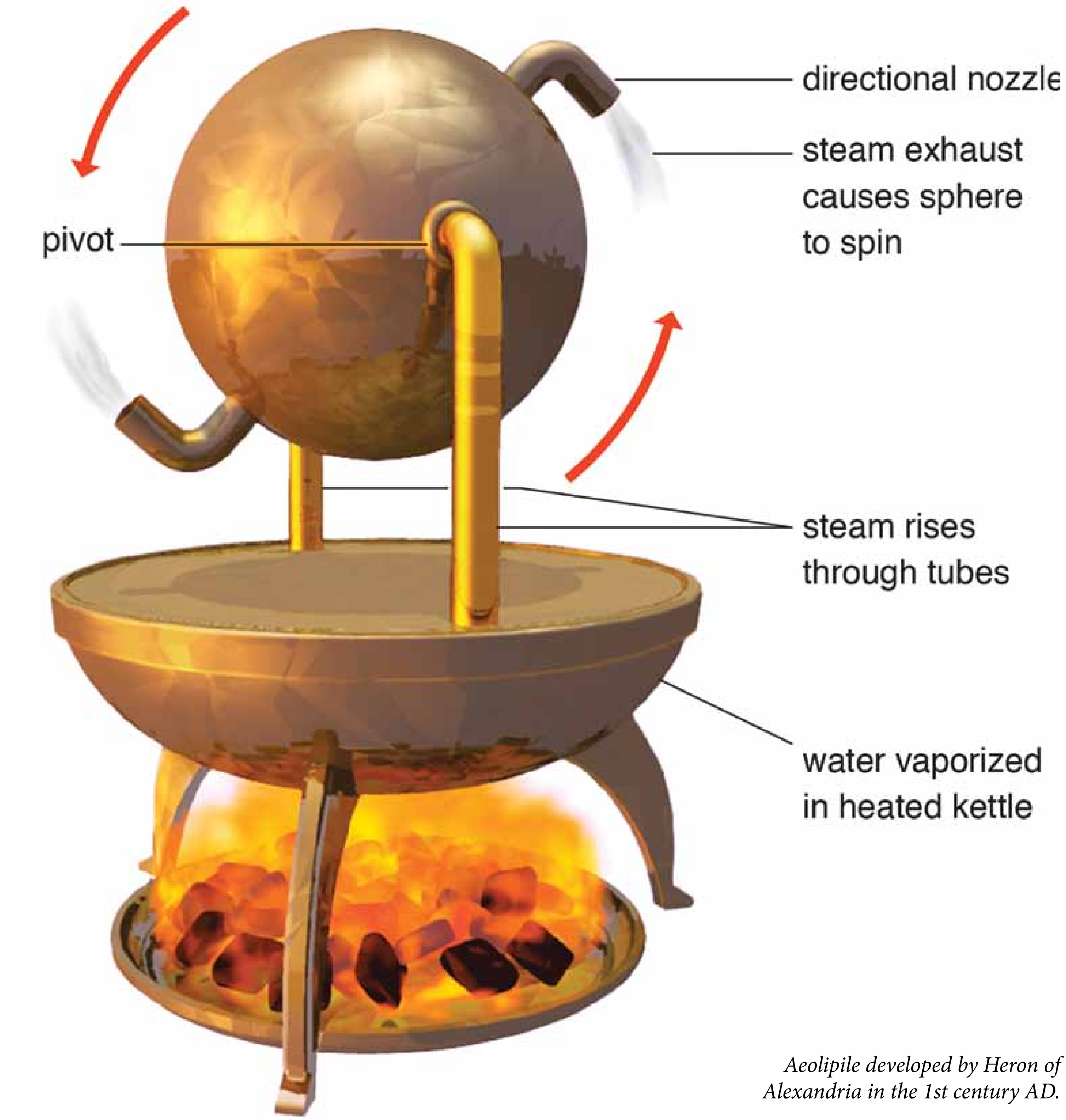
The science of thermodynamics has intrigued and fascinated scientists, engineers and mathematicians for centuries. The laws of thermodynamics are of fundamental nature which makes them also applicable to several other fields of study far removed from the science of heat engines.

BY | DUDLEY BASSON

Possibly the first example of a working steam engine was the Aeolipile developed by Heron of Alexandria in the 1st century AD. This consisted of a closed vessel mounted on pivots, and with two tangential nozzles at right angle to the axis. When steam was introduced to the vessel, either through the pivots or by boiling water within the vessel, it would spin about the axis. This was merely a curiosity without any practical use. In modern parlance this would be described as a reaction turbine. No further development of heat engines would be done for fifteen centuries.

ROBERT BOYLE (1627 – 1691) and Galileo Galilei (1564 –1642) are regarded as two of the founders of modern science. Boyle was born in Lismore, County Waterford, Ireland, son of a wealthy landowner. He produced a prodigious output of works on scientific and theological matters. His book The Sceptical Chymist is seen as a cornerstone work in chemistry. Boyle is also famous for Boyle's Law which states that the product of pressure and volume of a gas remains constant at constant temperature, giving: $P1\ V1 = P2\ V2$. This would be later combined with Charles's Law and Gay-Lussac's Law giving: $P1\ V1 / T1 = P2\ V2 / T2$ for absolute temperatures - a fundamental relation in thermodynamics. Denis Papin (1647–1712) worked with Boyle from 1676 to 1679 and later also with Huygens and Leibniz. He was the first to build a pressure cooker and also in 1690, the first to build a piston driven steam engine. In 1704, he constructed a ship, powered by his steam engine, which was mechanically linked to paddles.

THOMAS SAVERY (c. 1650–1715) produced the first commercially available steam engine. This was used for pumping water from mines. The device had no moving parts except for the taps controlling the flow of water and steam. A vessel and a downpipe into the water were filled with steam. The steam valve was then shut and the vessel cooled so that the partial vacuum would draw water up into the vessel.



Aeolipile developed by Heron of Alexandria in the 1st century AD.

The downpipe valve was then shut and a riser pipe opened so that pressurised steam could then force water up the riser pipe. The range of the suction and riser pipes was very limited so that a series of these devices would be needed to raise water to any great height. This device was not remarkable in that it worked so well, but that it worked at all. The alternative was to use buckets attached to ropes.

THOMAS NEWCOMEN (1664–1729), an ironmonger by trade, created the first practical steam engine for pumping mine water using ideas from Savery and Papin. This was a piston driven beam engine which could raise water by means of a long chain operating a pump at the base of the mine. The steam generator was similar to a brewer's kettle placed beneath the cylinder. The cylinder was filled with steam, and then cooled, so that the partial vacuum would produce the power stroke. This engine was not thermally efficient but this was not a

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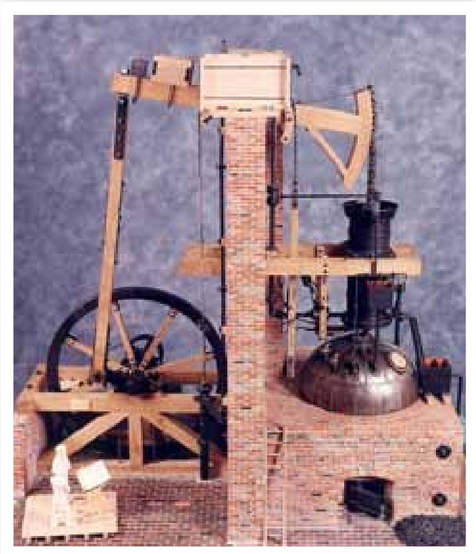

Newcomen Engine

problem at collieries where much waste coal was available. Newcomen and his partner John Calley built the first successful engine of this type at the Conygree Coalworks in 1712 near Dudley in the West Midlands. The Newcomen engine held its place without material change for about 75 years, spreading to other parts of the country and also to Europe. Many hundreds were built, some having a cylinder of as much as six feet in diameter.

LEONHARD EULER (1707-1783) was one of the greatest mathematicians of all time. He had a huge range of interests in many branches of science. Some of his advanced mathematical work would later have a direct bearing on studies of the intrinsic and extrinsic properties of thermodynamic fluids.

JAMES WATT (1736-1819) initially had a career as an instrument maker and also produced a number of inventions. He is most famous for his radical improvements to the steam engine which greatly benefited the Industrial Revolution.

Watt introduced the power unit 'horsepower'. This was important at a time when horses were competing with, and being replaced, by steam engines. This was an easily understood means of expressing the capabilities of the engines. The original horsepower was the power required to lift a 550 lbs weight at a rate of one foot per second. This gives a SI equivalent of 745,69987 W. When the output of electric motors is expressed in horsepower this is taken as 746 W. In Europe a metric horsepower is used. The German *Pferdestärke* is 735,49875 W.

The SI power unit 'watt' is a derived unit of one joule per second. This can also be expressed as one volt-ampere in a DC circuit. In an AC circuit the RMS values must be used as well as a power factor if the voltage and current are not exactly in phase.

In SI base units the watt is expressed as: $m^2 kg\, s^{-3}$. Boulton and Watt were featured on the 2009 issue of the £50 Bank of England banknote.

A huge statue of Watt in London bears the inscription: "James Watt ... enlarged the resources of his country, increased the power of man, and rose to an eminent place among the most illustrious followers of science and the real benefactors of the world."

JEAN-BAPTISTE JOSEPH FOURIER (1768-1830) made a major contribution to the study of heat flow in his work "Analytical Theory of Heat" (Théorie analitique de la chaleur). This was not only useful for Napoleon's overheating cannons, it also provided the theory of Ricci flow, somewhat similar to heat flow, which played a vital part in the proof of Poincaré's famous topology conjecture two centuries later. The famous Fourier Series and Fourier Transform would later become fundamental to the study of harmonics in electrical engineering. The Fourier Series is usually expressed as a series of trigonometrical terms but can also be expressed as a series of complex number exponential terms.

In the 17th century Becher and Stahl introduced the idea that heat was a substance which they named 'phlogiston'. In 1770 chemistry pioneer Lavoisier explained combustion in terms of oxygen and introduced the term 'caloric' as the subtle fluid substance of heat. In 1782 Lavoisier and Laplace developed the first calorimeter which measured the heat involved in chemical reactions. The caloric theory would eventually be superseded by the kinetic molecular theory of heat but the caloric theory provided useful insights quite compatible with the kinetic theory.

Fourier, unlike Lavoisier, was fortunately able to keep his head and body connected during the French Revolution. Fourier coined the 'greenhouse' analogy to describe the similarity between the Earth's atmosphere and the glass of a greenhouse in trapping solar heat. Fourier also played a key part in the decipherment of the Rosetta stone by taking an ink impression which Champollion was able to use in the decipherment of the hieroglyphics.

ROBERT STIRLING (1790-1878) a Scottish clergyman, developed his remarkable air engine in 1816. This efficient engine has air as an enclosed thermodynamic fluid and heat is applied externally which can be from any convenient source of heat. The engine can

have either two cylinders with pistons or one cylinder with two pistons. The hot expansion (displacer) piston does not seal the cylinder but allows air to pass to the compression cylinder which is cooled. This engine is remarkable in its simplicity without any valves, and quiet operation. This engine may see a major revival as it is well suited to power generation from concentrated solar power or combustion of waste material.

NICOLAS LÉONARD SADI CARNOT (1796-1832) has been described as the father of thermodynamics. At age 16 Sadi became a cadet at the École Polytechnique which had been founded by his father Lazare Carnot and Gaspard Monge in 1794, as a military academy. The academic staff included several renowned scientists and mathematicians. The eighteen year old Sophie Germain was not permitted to enrol but mathematician Lagrange, recognising her brilliance, became her private mentor.

In 1824 Sadi published his *"Reflections on the Motive Power of Fire"* (Réflexions sur la puissance motrice du feu et sur les machines propres à développer cette puissance) which gave the first successful theory of the maximum efficiency of heat engines. This was later used by Clausius and Lord Kelvin to formalize the second law of thermodynamics, and define the mathematical concept of entropy.

Hot temperature	Efficiency
200 ^{0}C	34,9 %
300 ^{0}C	46,2 %
373,6 ^{0}C	52,4 %
400 ^{0}C	54,2 %

Carnot's idealized four process heat engine with the theoretically maximum possible thermal efficiency is fundamental to thermodynamics. This showed that the maximum efficiency was determined only by the temperatures of the hot source and cold sink and not by the nature of the thermodynamic fluid. The efficiency is given by: $\eta = (T_H - T_C) / T_H$ with absolute temperatures.

This gives some sobering results, using a cold sink temperature of 35^{0}C:

This efficiency is not attainable in practice which means that more than half of the energy of a power station's coal combustion can be seen wafting away from the cooling towers as clouds of vapour. It would make a huge difference if commercial use could be found for large quantities of hot water but this is seldom the case.

It is interesting to note that Carnot's work relied on the caloric theory of heat. Even though caloric does not actually exist as a substance, it has served a useful purpose in early thermodynamic study. Carnot's groundbreaking work received little recognition in his lifetime. He died at age 36 suffering from cholera.

JAMES HALL NASMYTH (1808-1890) was a Scottish engineer and inventor, famous for his development of the steam hammer. His father Alexander Nasmyth was an accomplished landscape and portrait painter, and had a home workshop where he encouraged James to work in all sorts of materials. Alexander became a close friend of poet Robert Burns. He taught his pupils Euclidean geometry in order to explain the principles of perspective. He was an art tutor of the child who would become the famous mathematician and scientist, Mary Somerville. James made his first steam engine aged 17, in his father's workshop. In 1828 he made a steam carriage capable of carrying eight people. James worked as a draughtsman and managed by age 23, to save the princely sum of £69, with which

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he set up his own business in a factory flat. The business came to an abrupt end when the end of a heavy engine beam crashed through the floor into the premises of a glass cutter below. His new premises were constructed adjacent to the Liverpool and Manchester Railway and the Bridgewater Canal.

In March 1838, on a coach journey from Sheffield to York in a snowstorm, James noticed ironwork furnaces in the distance. The coachman informed him that the works were managed by a customer of his, a Mr. Hartop, originally from Woodburn, Yorkshire. James walked through the snow and found Mr. Hartop at home with his family. He was invited to spend the night. James was instantly smitten by Hartop's 21 year old daughter Anne. Not being a man to waste time, they were betrothed the next day and married two years later. They remained happily married for fifty years until his death.

Nasmyth, Gaskell & Co. concentrated on producing a wide range of machine tools in large numbers. By 1856, Nasmyth had built 236 shaping machines. Isambard Kingdom Brunel was straining the manufacturing resources of the country with huge projects which included vast railways and gigantic steamships. Nasmyth had to produce machine tools of unusual size and great power to cope with the construction of huge marine engines. There was no forge hammer in England that could cope with the paddle shaft of the *SS Great Britain,* which prompted Nasmyth to design his famous steam hammer. He took pleasure in demonstrating his hammer by first breaking an egg in a wineglass without breaking the glass and then let the hammer do a full power thump which shook the building. A total of 490 hammers were produced of which many were sold in Europe, Russia, India and Australia.

Nasmyth developed a steel making process which was taken further by Bessemer, who acknowledged Nasmyth's contribution, and offered him a third share in the patent.

Nasmyth retired in 1856 after a very eventful and successful life in engineering, to pursue his hobbies of photography and astronomy. He built his own 20 inch reflector telescope. At this time it was not possible to take photographs of the Moon through a telescope, so he made plaster models of the craters and photographed those. Nasmyth is also famous for devising the Nasmyth focal point of a telescope. A mirror inside the telescope reflects light through the hollow spindles and trunnions of the vertical movement to a detection instrument mounted on a platform beside the telescope. By this means the camera, spectrograph or other instrument can be in a fixed position without having to move as the inclination of the telescope is changed.

JAMES PRESCOTT JOULE (1818-1889) was the son of a wealthy brewer who himself managed the brewery as an adult. James was fascinated by electricity and with his brother would experiment giving each other shocks as well as shocking the family's servants. As a young man of 22 he investigated the possibility of replacing the brewery's steam engines with the newly invented electric motor. In 1841 he discovered 'Joule's first law' that stated the heat power obtained from a current passing through a resistor is proportional to the square of the current and the resistance: $W = I^2R$. He also discovered that burning a pound of coal in a steam engine was more economical than consuming a pound of costly zinc in a battery. Joule's first law also disproved the caloric theory of heat, as heat could be produced without something else becoming colder. The scientific community of the day was very reluctant to discard the caloric theory, especially on the ideas of someone outside the academic and engineering professions. Joule did many experiments to precisely determine the mechanical equivalent of heat. In August 1843 he stated: *"Wherever mechanical force is expended, an exact equivalent of heat is always obtained"*. Joule's idea of a kinetic molecular theory of heat met with much resistance, especially due to the existence of atoms and molecules not being widely accepted at the time.

The SI unit of energy has been named the 'joule' in his honour.

One joule = one newton-metre. The SI units are coherent so that a joule can also be expressed as one volt-ampere-second.

Joule's second law states: The internal energy of an ideal gas is independent of its volume and pressure, depending only on its temperature.

WILLIAM JOHN MACQUORN RANKINE, FRSE FRS (1820 –1872) was a man of many talents. Mechanical engineer, civil engineer, physicist and mathematician. He was also an enthusiastic amateur musician - singer, pianist and 'cellist' who composed his own humorous songs.

In 1836 he studied a spectrum of scientific topics at the University of Edinburgh including natural history and natural philosophy. He was awarded a prize for his essay on the undulatory theory of light.

Working for the Irish Railway he developed *"Rankine's method"* for laying out railway curves, fully exploiting the theodolite.

The year 1842 marked Rankine's first attempt to reduce the phenomena of heat to a mathematical form. By 1849, he had succeeded in finding the relationship between saturated vapour pressure and temperature. The following year, he used his theory to establish relationships between the temperature, pressure and density of gases, and expressions for the latent heat of evaporation of a liquid.

He accurately predicted the surprising fact that the apparent specific heat of saturated steam would be negative.

From 1854, he made wide use of his *thermodynamic function* which he later realised was identical to the entropy of Clausius.

Rankine was also the first to discover 'metal fatigue' which was propagated from brittle cracks. This was a serious problem which had resulted in railway crashes.

RUDOLF JULIUS EMANUEL CLAUSIUS (1822 – 1888) is considered one of the central founders of thermodynamics. In restating Carnot's 'Carnot Cycle' he put the theory of heat on a sounder basis. In his most important 1850 paper *"On the Moving Force of Heat"* he stated the basic ideas of the second law of thermodynamics.

His most famous statement of the second law of thermodynamics published in 1854: *Heat can never pass from a colder to a warmer body without some other change, connected therewith, occurring at the same time.*

In 1865 Clausius defined the mathematical concept of entropy and named it from the Greek meaning 'transformation content' and also stated the first and second laws of thermodynamics.

The laws of thermodynamics can be concisely stated as follows:

1. If two systems are in thermal equilibrium with a third system then they must be in equilibrium with each other. (This defines the notion of temperature).

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2. The energy of the universe is constant. (Energy/matter cannot be destroyed).
3. The entropy of the universe tends to a maximum.
4. The entropy of a system approaches a constant value as the temperature approaches absolute zero. (The entropy of a system at absolute zero is typically close to zero, and is equal to the logarithm of the multiplicity of the quantum ground states).

Some comments on Clausius by Willard Gibbs (an American physicist, chemist and mathematician): *"Before Clausius, truth and error were in a confusing state of mixture, and wrong answers were confidently urged by the highest authorities."*
"The work of Clausius lies not on the shelves of libraries, but in the thoughts of men, and in the history of more than one science." The collected sixteen papers of Clausius published in two volumes constitute a huge contribution to science. In his 1875 textbook *"The Mechanical Theory of Heat"*, Clausius gives 448 numerically listed equations as well as the ten fundamental equations of thermodynamics.

Entropy can be illustrated by means of the pieces of a jigsaw puzzle. When the puzzle is assembled the entropy will be low. When the loose pieces are in a box the entropy will be high and no amount of shaking will ever result in the puzzle becoming assembled.

The entropy can of course be lowered by assembling the puzzle, but this will require an input of intelligence, human or computer. In thermodynamics the entropy can be lowered by an input of heat or mechanical energy. Entropy also represents the availability of energy. Take two containers of fluid, one hot and the other cold.

This represents available heat at low entropy which can be used to drive a heat engine. If the fluids are brought together or mixed the entropy will rise and the heat will become unavailable for use even though no energy has been lost. This can also apply to heaps of building material.

WILLIAM THOMSON, 1st Baron Kelvin (1824 –1907) was born in Belfast to James Thomson, a teacher of mathematics and engineering, and Margaret née Gardiner. He did important work in the mathematical analysis of electricity and formulation of the first and second laws of thermodynamics, at the University of Glasgow.

He is widely known for determining the temperature of absolute zero as -273,15^{0}C. The SI unit of absolute temperature 'kelvin' (symbol K) is named in his honour. The triple point temperature of water is 0,01^{0}C or 273,16 K.

In the academic year 1839/1840, Thomson won the class prize in astronomy for his *Essay on the figure of the Earth.*

The Thomson children were introduced to a broad cosmopolitan experience spending mid-1839 in London, and the boys, being tutored in French in Paris. Mid-1840 was spent in Germany and the Netherlands. Language study was given a high priority.

Thomson became intrigued with Fourier's *'Théorie analytique de la chaleur'*. The book motivated Thomson to write his first published scientific paper defending Fourier, which was submitted to the Cambridge Mathematical Journal. At Cambridge in 1845 Thomson graduated as Second Wrangler. He also won a Smith's Prize, which, unlike the tripos, is a test of original research. Robert Leslie Ellis, one of the examiners, is said to have declared to another examiner *"You and I are just about fit to mend his pens."*

In 1847 Thomson attended a meeting in Oxford where Joule made an attempt to discredit the caloric theory and Carnot's theory of the heat engine. Joule argued for the equivalence of heat and mechanical energy. In 1849 Thomson was the first to use the term 'thermo-dynamic'. He was knighted by Queen Victoria in 1866 for his work on the transatlantic telegraph project.

Thomson was honoured with the title 1st Baron Kelvin of Largs in 1892 for his contributions to thermodynamics and his opposition to Irish Home Rule. Kelvin is the name of a river flowing close to Glasgow University.

Between 1870 and 1890 a theory claiming that an atom was a vortex in the ether was immensely popular among British physicists and mathematicians. About 60 scientific papers were written by some 25 scientists. Following the lead of Thomson and Tait, the branch of topology known as knot theory was developed. Kelvin's initiative in this complex study of topological manifolds continues in modern string theory of subatomic particles. In all, Thomson published 661 scientific papers.

PETER GUTHRIE TAIT FRSE* (1831-1901) was a Scottish mathematical physicist. He is best known for his energy physics textbook *Treatise on Natural Philosophy,* which he co-wrote with Kelvin. Tait spent considerable time in investigations into knot theory of mathematical topology and devised topological knots of up to ten crossings to represent vortex atoms.

In 1860, Tait succeeded his old master, JD Forbes, as professor of natural philosophy at Edinburgh. After meeting mathematician Hamilton he became a leading exponent on quaternions. He also made considerable contributions to thermodynamics. James Clerk Maxwell and Peter Guthrie Tait both enrolled at the Edinburgh Academy as young lads – their brilliant academic careers would remain inextricably linked for many years.

JAMES CLERK MAXWELL (1831–1879) is of course most famous for his epoch making mathematical theory of electromagnetic radiation. He also did pioneering work on colour theory and photography. Maxwell collaborated with **JOSIAH WILLARD GIBBS** (1839-1903) in advanced studies of thermodynamics, raising the science to new heights of mathematical analysis.

Maxwell posed a light hearted puzzle on how to trick the law of entropy and produce heat without fuel or other energy input. This was "Maxwell's Demon", a clever little fellow but not quite clever enough. The demon's task was to control a gate between two containers of fluid, letting fast (hot) molecules pass the one way and slow (cold) molecules pass the other way. This would result in the one container becoming heated, and the other refrigerated, producing available energy at lower entropy which could be used to drive a heat engine. There was a problem in how the demon would know which molecules were fast and which were slow.

Scientist and computer pioneer John von Neumann showed that the demon idea could not work because units of information are also subject to the law of entropy.

In 1866, Maxwell published his *"On the Dynamical Theory of Gases"*, showing how, through kinetic theory, to obtain physical properties of gases from the underlying distribution of velocities (Maxwell-Boltzmann distribution). This is claimed as an analytical proof of the second law of thermodynamics.

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JOSIAH WILLARD GIBBS (1839 –1903). His work on the applications of thermodynamics was instrumental in transforming physical chemistry into a rigorous deductive science. He entered Yale College in 1854, aged 15 and graduated in 1858. He was awarded prizes for excellence in mathematics and Latin. In 1863 he received the first PhD in engineering granted in the US, for his thesis on the geometrical form of gearwheel teeth.

Gibbs travelled to Europe with his sisters spending the winter of 1866–67 in Paris, where he attended lectures at the Sorbonne and the Collège de France. Moving to Berlin, Gibbs attended lectures by mathematicians Weierstrass and Kronecker. At the time, German academics were the leading authorities in the natural sciences, especially chemistry and thermodynamics. Maxwell included a chapter on Gibbs's work in the 1875 edition of his *Theory of Heat*. He explained the usefulness of Gibbs's graphical methods in a lecture to the Chemical Society of London and even referred to it in the article on "Diagrams" that he wrote for the *Encyclopædia Britannica.*

Gibbs extended his thermodynamic analysis to multi-phase chemical systems and considered a variety of concrete applications. He described that research in a monograph titled "On the Equilibrium of Heterogeneous Substances", published by the Connecticut Academy in two parts that appeared respectively in 1875 and 1878.

That work, which covers about three hundred pages, contains exactly seven hundred numbered mathematical equations based on the original 458 equations of Clausius.

Together with James Clerk Maxwell and Ludwig Boltzmann, Gibbs founded "statistical mechanics", a term that he coined to identify the branch of theoretical physics that accounts for the observed thermodynamic properties of systems in terms of the statistics of large ensembles of particles.

Gibbs made a major contribution to mathematics by devising the dot and cross products of vector algebra (independently of Heaviside). Gibbs was regarded by Albert Einstein as "the greatest mind in American history".

LUDWIG EDUARD BOLTZMANN (1844 –1906)
Building on Maxwell's work, Boltzmann developed what he called a 'minimum theorem', in his famous 1872 paper "Further Studies on the Thermal Equilibrium of Gas Molecules", which derived a kinetic expression for the entropy of an ideal gas.

JULES HENRI POINCARÉ (1854 –1912) is most famous for his huge contribution to mathematical topology. He also studied *thermodynamics* to an advanced level and published his book Thermodynamics in 1892. As a young man he worked as a mining engineer at a coal mine. Poincare is said to have concluded that classical thermodynamics and Hamiltonian dynamics were incompatible, because no function of coordinates and momenta could have the properties of the Boltzmann entropy function.

MAX KARL ERNST LUDWIG PLANCK (1858-1947) came from a family of distinguished academics. He was musically gifted taking voice lessons as well as piano, organ and 'cello. In 1877 he went to Berlin where he studied under the famous physicists von Helmholtz, Kirchoff and mathematician Weierstrass.

In 1879 he presented his dissertation 'On the second fundamental theorem of the mechanical heat theory' (entropy) and in 1880 his thesis 'Equilibrium states of isotropic bodies at different temperatures'. He became an associate professor at Kiel University in 1885 and furthered his work on entropy, especially as applied to physical chemistry.

Planck complained that his thermodynamics students seemed to have difficulty grasping the concept of entropy, regarding it as a mathematical spook. The abstruse nature of entropy also puzzled Sir James Swinburne FRS* (1858-1958), electrical engineer and plastics manufacturer, who commented: *"As a young man I tried to read thermodynamics, but I always came up against entropy as a brick wall that stopped my further progress. I found the ordinary mathematical explanation, of course, but no sort of physical idea underlying it. No author seemed even to try to give any physical idea. Having in those days great respect for textbooks, I concluded that the physical meaning must be so obvious that it needs no explanation, and that I was especially stupid on the particular subject."*

Planck's research in thermodynamics led to his epoch making discovery of quantum theory for which he was awarded the 1918 Nobel Physics Prize.

ERWIN RUDOLF JOSEF ALEXANDER SCHRÖDINGER (1887 - 1961) is most famous for his wave equation mathematically describing the wave nature of physical particles. He wrote on a wide

range of topics including his "Statistical Thermodynamics" in 1946. His book "What is Life" is a classic. He also deals with the lowering of entropy in nature. He proposed that living creatures were specified at molecular level, before the discovery of DNA.

JOHN VON NEUMANN (1903 - 1957) was one of several Hungarian scientists and mathematicians who emigrated to the US early in the 20th century. They became known as "The Martians" for their other worldly mathematical and scientific brilliance and incomprehensible home language. Von Neumann made huge contributions to science and mathematics including nuclear fusion and the H-bomb. He was also a pioneer of computer science. He was able to prove mathematically that Schrödinger's wave mechanics and Heisenberg's matrix mechanics were mathematically equivalent.

Claude Shannon (the father of information technology), in conversation with von Neumann, regarding what name to give to the attenuation in phone-line signals:
I thought of calling it "information", but the word was overly used, so I decided to call it "uncertainty". Von Neumann told me: "You should call it entropy, for two reasons. In the first place your uncertainty function has been used in statistical mechanics under that name, so it already has a name. In the second place, and more important, nobody knows what entropy really is, so in a debate you will always have the advantage."

The SI unit of pressure has been named the 'pascal' (symbol Pa) in honour of the famous polymath **BLAISE PASCAL** (1623-1662). This is a derived unit of one newton per square metre. Other units of pressure which are still sometimes in use are the 'bar', 'p.s.i.' (pounds per square inch) and atm (atmosphere). The following table shows some pressure conversions - the pressure for supercritical water has been highlighted.

p.s.i.	kPa	bar	atm
1	6,8948	0,06895	0,06805
14,5038	100,0	1,0	0,9869
72,5189	500,0	5,0	4,9346
145,038	1000,0	10,0	9,8692
1000	6894,8	68,95	68,05
1450,38	10 000,0	100,0	98,692
3200,11	22 064,0	220,64	217,755
5000	34 473,8	344,738	340,229
10 000	68 947,6	689,476	680,459

Early power stations were of the Stirling design with multiple boiler drums and steam/water separator. The thermal efficiency of these power stations was in the 30-35% range. A large number of different water tube boiler designs have been in use over the years. As indicated by the Carnot cycle, it is necessary to increase the temperature of the thermodynamic fluid in order to improve the efficiency.

This indicates the use of supercritical water as the thermodynamic fluid, requiring a radical redesign of the steam generating plant. Supercritical water has a minimum temperature of 373,597^{0}C and a minimum pressure of 22,064 MPa (3200,11 psi).

A supercritical fluid has some unusual properties. There is no distinction between liquid and vapour; there is no liquid/vapour boundary so that droplets cannot form; fluids which are normally not miscible become fully miscible in the supercritical state. The density of the supercritical fluid is lower than that of the liquid state. Supercritical fluids do not only apply to water, they are also used in the manufacture of decaffeinated coffee and in the extraction of essential fragrance oils.

A supercritical power station does not have a boiler as boiling cannot take place. In the steam generating plant the fluid is contained entirely within the tubes. A drum containing some tons of supercritical water could potentially demolish the entire power station. Fortunately, tubes can be manufactured to safely withstand any industrial pressure. Welding of the tubes must of course be done with great expertise and will also require post-welding heat treatment and inspection.

The supercritical fluid from the furnace is taken to the high pressure turbine where it is released as superheated dry steam. The exhaust steam is no longer supercritical but is able to benefit from a pass through the superheater tubes before going to the intermediate and low pressure turbines.

The exhaust steam from the low pressure turbine passes to the condenser which controls the exhaust pressure, keeping it low enough to prevent any back pressure, but not causing droplets to form inside the turbine. Heat extracted by the condenser is normally allowed to go to waste in cooling towers or other methods of heat disposal. Condensate from the condenser is then pumped at supercritical pressure through the economiser which extracts heat from a cooler part of the furnace before re-heating. Heat is also extracted from the flue gases by a heat exchanger which preheats the air supply to the furnace. Coal in pulverised form is blown into the furnace. The thermodynamic fluid is purified

From Kettles to Supercritical

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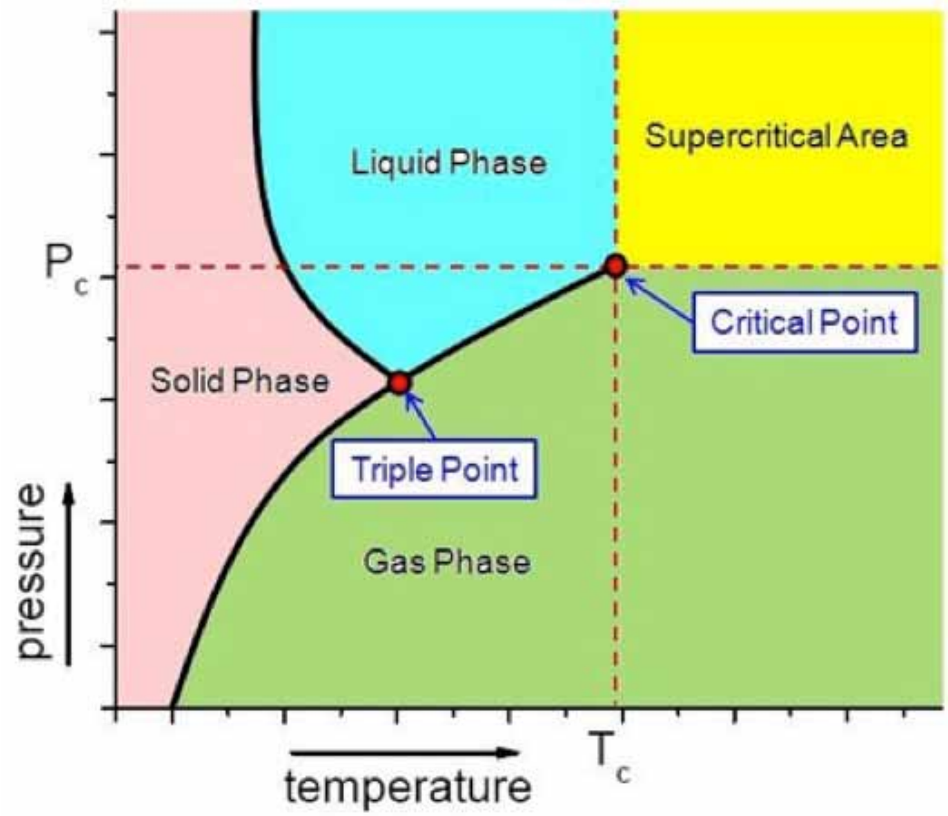


oxygen free water which is continuously circulated. If it is required to improve the power station efficiency even further, it becomes necessary to consider ultra-supercritical water. The furnace, turbine, condenser circuit of the thermodynamic fluid is represented by the Rankine cycle.

There are several thermodynamic processes which form the various heat engine cycles. Several named heat engine cycles have been defined.

Isobaric	Constant pressure
Isothermal	Constant temperature
Isochoric	Constant volume
Adiabatic	No heat added or lost
Isentropic	Constant entropy (reversible process)
Isenthalpic	Constant enthalpy

Some of the well known cycles are as follows:

Cycle	Compression	Heating	Expansion	Cooling	Usage
Carnot	isentropic	isothermal	isentropic	isothermal	Ideal cycle
Rankine	adiabatic	isobaric	adiabatic	isobaric	Steam engine
Stirling	isothermal	isochoric	isothermal	isochoric	Stirling engine
Brayton	adiabatic	isobaric	adiabatic	isobaric	Jet engine
Diesel	adiabatic	isobaric	adiabatic	isochoric	Diesel engine
Otto	adiabatic	isochoric	adiabatic	isochoric	Petrol engine

The Carnot cycle is an idealised theoretical cycle which does not represent any practical heat engine. The processes of the cycles are not all strictly accurate. The adiabatic expansion in internal combustion engines does include some heat loss through the cylinder walls which is carried away by the cooling system. Most of the heat loss is however through the exhaust gases.

P-V (pressure-volume) diagrams are commonly used to illustrate the cycles. The area enclosed by the four curves represents the mechanical output. T-S (Temperature-entropy) diagrams are widely used in thermodynamic study. Enthalpy is an energy term commonly used in thermodynamics – this represents the internal heat energy of a gas with the pressure-volume product added.

The assembled shaft of a turbo-alternator is a complex dynamic system of several heavy masses sharing a common shaft. These will have natural torsional oscillations, which if aggravated by sub-synchronous resonances in a transmission line, could result in catastrophic shaft failure. Sub-synchronous resonances can occur in a long transmission line that has been provided with capacitors for power factor correction. The turbines and alternator have widely spaced bearings which can result in slight sags in a stationary shaft. Before the turbo-alternator is powered, the sags must be removed by barring (slow rolling) the set, but fast enough to maintain the bearing oil films. Barring speed can be from a few revolutions per minute to a few tens of revolutions per minute. If the set is partly disassembled, barring must be done manually at regular intervals with the assistance of an overhead crane. A permanent deformity in the set will require return to the manufacturer for reconditioning. When the turbo-alternator is shut down from service it must be slow rolled for up to 24 hours to ensure that all

parts have cooled equally. A stationary hot alternator rotor will become hotter at the top than the bottom causing it to bow upwards and possibly make contact with the stator. The shaft deformities are variously called: sag, bow, smile, frown, hogging, cat-back and humping. Barring an alternator rotor can cause 'copper dusting' due to friction between the conductors and slot insulation.

This does not happen under load. It is vitally important that slot insulation be uniform throughout the rotor as uneven heat flow could cause rotor deformation. Partial insulation failure between rotor windings can also result in uneven temperatures. It should not be supposed that the alternator rotor is like a floppy piece of wors. It is an extremely heavy and rigid piece of machinery and the deformations are measured in microns. An auxiliary machine will usually be included at the alternator end of the shaft. This is a DC generator for providing current for excitation of the alternator rotor.

The high pressure turbines are normally in matching pairs with steam supplied to the centre and flowing outwards to balance the enormous axial thrust. The other turbines are also matched to reduce axial thrust as much as possible. Axial thrust is further reduced by a dummy piston on the shaft with steam pressure. Steam leakage from the shaft is controlled by labyrinth seals. These do not make complete contact with the shaft but reduce steam escape by means of small steam vortices within the labyrinth. The shaft must of course also have thrust bearings to deal with any unbalanced axial thrust. The temperature of the Babbitt metal and slight axial movement of the shaft must be continuously and meticulously monitored. At the first hint of thrust bearing failure the thrust must be relieved within 30 seconds in order to prevent catastrophic failure.

Hydrogen is commonly used as the internal coolant for alternators. Its low density, high specific heat and thermal conductivity make it up to ten times better than air. Water cooling can be used for the stator. Despite their complexity, turbo-alternators are designed for very long and reliable service life.

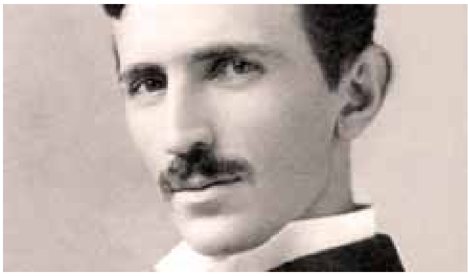
Research is underway to develop Generation IV nuclear concepts to improve the thermal efficiency of nuclear power plants by the use of supercritical water, from the current 30-35% range to the 45-50% of modern supercritical power plants. It is envisaged that a single circuit of fluid for both reactor and turbines would be used instead of separate fluid circuits connected by a heat exchanger.

Designing a nuclear reactor vessel to safely withstand the pressure of supercritical water presents some huge challenges. The differing neutron moderating properties of subcritical and supercritical water could also be problematic.

Nuclear reactors sometimes use liquid metal coolants such as sodium, as the high boiling point removes the need for a pressurised vessel. The heat is transferred to the high pressure turbine circuit through a heat exchanger. Sodium is an alkali metal with a melting point of 97,72^{0}C and a boiling point of 882,94^{0}C.

Molten sodium has an advantage in that it is electrically conductive and can be pumped by means of an electromagnetic pump. Care must be taken with sodium as it can spontaneously catch fire in air and explode on contact with water.

Internal combustion engines and steam driven power plants have reached astonishing levels of development and sophistication, however their future is by no means secure. Huge efforts and research are being done to develop environmentally friendly and renewable sources of power supply and means of propulsion.



NIKOLA TESLA (1856–1943) made astonishing contributions to electrical engineering and also did much pioneering work on high voltage and high frequency power. Tesla also had a vision of obtaining 'universal' power directly from nature as evidenced by a quotation:
Ere many generations pass, our machinery will be driven by a power obtainable at any point of the universe. This idea is not novel. Men have been led to it long ago by instinct or reason; it has been expressed in many ways, and in many places, in the history of old and new. We find it in the delightful myth of Antheus, who derives power from the earth; we find it among the subtle speculations of one of your splendid mathematicians and in many hints and statements of thinkers of the present time. Throughout space there is energy. Is this energy static or kinetic! If static our hopes are in vain; if kinetic — and this we know it is, for certain — then it is a mere question of time when men will succeed in attaching their machinery to the very wheelwork of nature. wn

** FRS - Fellow of the Royal Society*

IN MY OPINION : BEV LAWRENCE

Thoughts on Generating Plant Performance Improvement

In the aftermath of the Second World War, South Africa experienced a rapid growth in its economy. This resulted in a huge demand for electric power, and Eskom embarked on a massive Plant expansion program.

BY | BEV LAWRENCE | FSAIEE

From 1960 to 1990 the installed capacity rose ten-fold, from 4 000 to 40 000MW!!! But in 1984 the de Villiers Commission into Eskom's activities, reported that the Utility's financial governance was weak, resulting in very high tariffs being passed on to the customers to fund the huge capacity expansion programs.

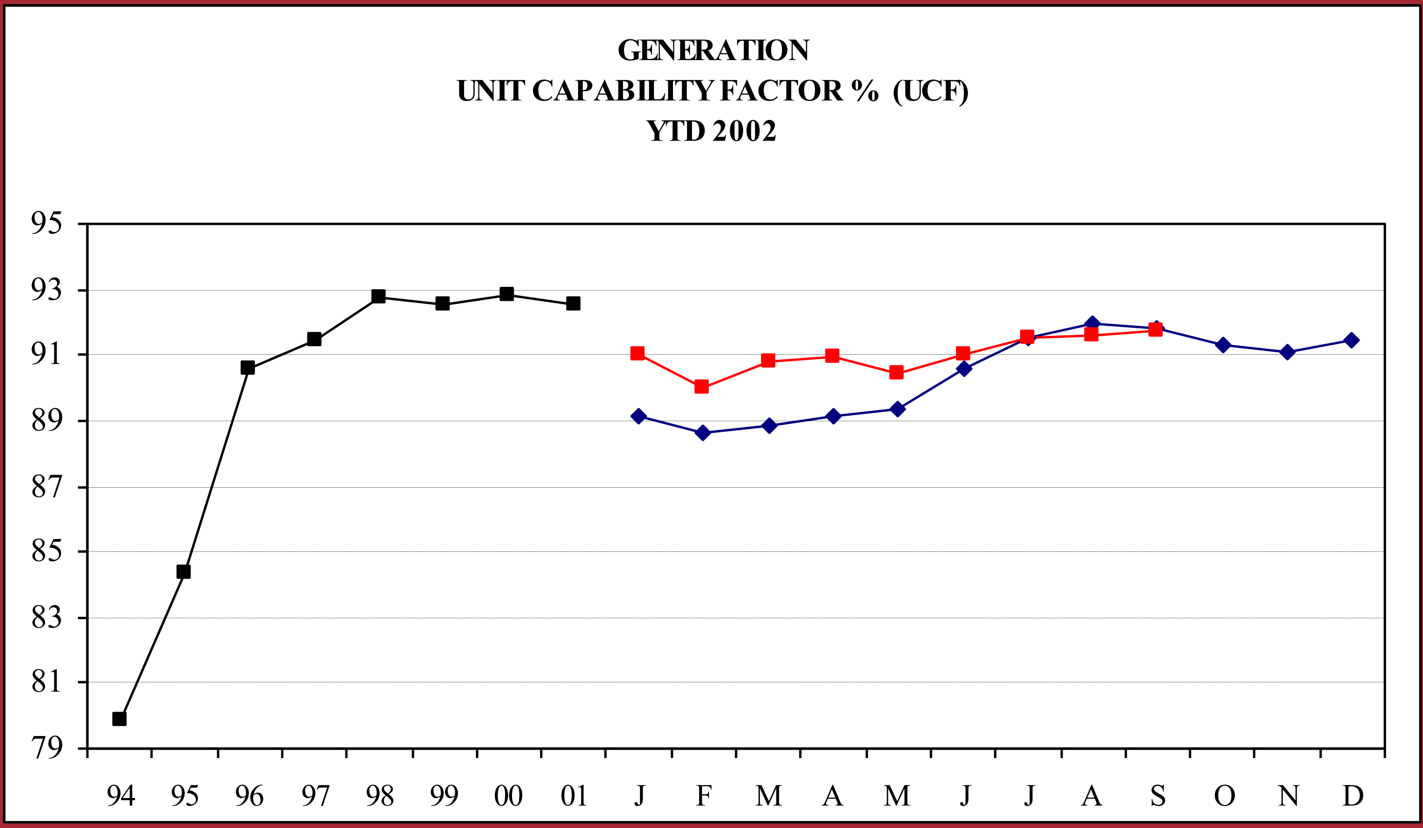
Accordingly the Government appointed the *"man of numbers"*, Dr John Maree, as Chairman with the "man of electricity", Dr Ian McRae, as CEO to deal with the problem, and this resulted in a total Eskom re-organisation. Amongst a number of changes, for the first time the power stations had an engineering capability on site, known as the Performance Enhancement section.

THE KENDAL PLANT PERFORMANCE IMPROVEMENTS

In 1986 I was appointed as Technical Services Manager at the new Kendal power station, and appointed several engineers in this section, who made many valuable contributions in identifying and rectifying the various design deficiencies in the plant. Particularly the Control and Instrumentation (C&I) aspects which were beyond the contractor's abilities to remedy!

Eskom periodically awarded the C&I contracts to contractors not previously used by them, presumably to diversify the number of suppliers available, and to spread the benefits to more companies. It invariably had huge ramifications for the station concerned, as the control system for a coal-fired unit is the most complex and fast-response in the world, and these contractors, although well experienced with other slower simpler systems, often do not appear to have had the experience to successfully create such systems.

Kendal's initial plant performance was shocking, with unit trips occurring on a daily basis, resulting in the Power Station and Construction Manager's early replacement. The new PSM, Mr Peter O'Connor, was a very driven person



who continually pushed the Operating, Maintenance and Technical departments to improve the performance to meet, or better, that achieved at the other Eskom stations.

At that time the average Eskom, and world, plant availability (UCF - Unit Capability Factor) was 80%, with annual unit trips (UAGS - Unit Automatic Grid Separations) from 20 upwards for a six-unit station. As a result of his leading, and the teams combined efforts, these targets were soon achieved at Kendal. But he then kept on driving the team to surpass this performance, culminating in new Eskom, and probably world, records of 96% UCF and 5 UAGS!!!

THE 90:7:3 CHALLENGE

The Generation Executive Director at the time, Mr Bruce Crookes, noted this amazing performance, and challenged the other power stations to improve their plant performance UCF from 80 to 90%, together with a Planned outage rate of 7%, and an Unplanned one of 3%. This was to be achieved within 3 years, the so-called 90:7:3 Challenge! Although the Power station managers complained and groaned under the burden of this "impossible" target, they sent their engineers to Kendal to discover how it had been achieved.

Armed with this information, they returned to their stations and, together with their Operating and Maintenance colleagues, started implementing the various strategies used. The outcome was that the average station availability met the target within two years, and surpassed it in the third (see graph)! This resulted in an extra 12% of the installed capacity at the time of 40 000MW being made available for generation, ie. 4800MW, thus saving the cost and lengthy lead-time of designing and constructing another large station!

ESKOM'S PRESENT PLANT PERFORMANCE PROBLEMS

Based on my experience gained in participating in, and watching in awe, as this amazing plant performance was achieved at Kendal, I would like to offer the following suggestions on how the current (no pun intended!) performance of Eskom could be improved.

MANAGEMENT FOCUS ON NON-PLANT ASPECTS

Organisations tend to focus on issues their leaders regard as important. Leaders tend to focus on things they know something about, and thus feel comfortable with. Eskom's management in this century appears to have concentrated on other aspects rather than Generation technical issues. This has resulted in plant performance being somewhat ignored, with the all important UCF (Unit Capability Factor, ie. availability) dropping from above 80 to nearly 65% over the past decade.

Whilst there was no load shedding from 31 March 2008 until recently, the plant performance has deteriorated gradually to its present shocking level of 65% UCF, resulting in constant load-shedding.

So the management of Eskom HAVE

Generating Plant Improvements

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to direct their focus to improving plant performance. This appears to be happening recently, with the appointment of a new CEO Mr Brian Molefe. Senior managers from Megawatt Park with plant experience have been seconded to power stations to direct the station's efforts towards improving this aspect, and hopefully this will place some emphasis on reducing plant problems.

ORGANISATIONAL EFFECTIVENESS

The WANO (World Organisation of Nuclear Operators) states that the success of a nuclear power station in avoiding serious accidents rests on two pillars – Organisational Effectiveness and CAP (Corrective Action Program). This is equally true for other non-nuclear plants.

The first pillar vital for good performance is Organisational Effectiveness. This is a "Holy Grail" that all organizations strive for, but not many really achieve. (It has been very thoroughly researched by many Schools of Business Leadership, and authors, such as Peters and Waterman as discussed in their interesting book "In Search of Excellence"). As a result the top management often address it in an attempt to improve the performance of their businesses.

In the early 70's, Eskom's power stations were managed by the Undertakings in each area. For some strange reason the early "giant" stations in the eastern Transvaal (Komati, Camden, Hendrina), fell under the Rand & OFS Undertaking, with Dr. McRae as Generation Manager.

I guess it was felt that this organisational model was ineffective, as in 1972 a new Undertaking, the Central Generating Undertaking, was formed to manage all of Eskom's power stations throughout the country, with Dr. McRae as Manager.

Then 6 years later this model was deemed to be ineffective, and on 1 July 1978 the CGU was disbanded, and the Distribution Undertakings reformed as Regions, responsible for both generation and distribution of power within their geographic borders. I think that CGU was regarded as far too large for one organisational group, employing half of Eskom's staff and consuming more than ¾ of its finances!

Then 7 years later, the new Chairman, Dr John Maree, and CEO, Dr McRae, visited all of the Regions to meet with their management teams. They inquired as to what Eskom was doing well, and what they were unsuccessful at. Two of the biggest problems emerging from these meetings were that the power station managers felt that the Regional Managers, to whom they reported, had Distribution backgrounds, and hence little appreciation of the issues involved in managing large power stations (a single large power station had more staff and budget than the entire distribution function!). In addition, although they were responsible for the management of these giant stations, they lacked the authority to do so.

Following this, on the 1 January 1986, the Regions were disbanded, and a Generation Group again created (as well as Transmission and Distribution Groups)!

Furthermore, the Power station managers were promoted to E-band with greatly enhanced powers, and a full organization covering all functions necessary, reporting to them.

Then in 2008, following the rolling blackout crisis, the very autonomous power station organisation was apparently regarded as inefficient for the skills shortages experienced, and the non-core functions were again centralised under Megawatt Park management. Notably, the Engineering and Training functions were removed from the Power Station Management – presumably "to improve organisational effectiveness"!

And so we come to 2015, where the poor organisational performance appears to be leading to suggestions of again decentralizing these vitally important functions to the Power Station Management. One wonders whether the top management will realise this, and implement a re-organisation with a de-centralised emphasis.

CONTRIBUTION OF IMPROVEMENT IN AVAILABILITY TO THE PRESENT SHORTFALL

One may ask to what extent an improvement in Generation Group UCF performance would alleviate the problems created in South Africa by the chronic lack of generation capability. Well, at present there is some 43 800 MW of installed capacity in Eskom. The 2000 MW of gas turbines should be removed from this and only used for emergencies, leaving 42 000 MW. The UCF has dropped to around 65%, so the available generation is only some 65% of 42 000 MW = 27 300 MW!

The Utility norm is to have 15% Reserve Margins. If this could be achieved in Eskom it would leave 85% of 42 000 = 35 700 MW available to meet the demand, which is more than adequate for SA's summer demand. In winter the margin can be reduced by scheduling major planned outages during the summer months, so a 7.5% margin could suffice. Then the available capacity rises to 92.5% of 42 000 = 39 000 MW. Again this is more than enough to meet the typical winter peak of 37 000 MW, which occasionally rises to 38 000.

At the present time, however, the generation is down by as much as 12 000 MW, ie. 30 000 MW, leaving the country woefully short of capacity. And so the gas turbines are operated at full capacity, resulting in the enormous fuel bill we are seeing.

There is also some 2 000 MW of IPP plant connected, using solar and wind power. The PV installations, however, do not really generate during the peaks, with only the new Kaqu 100 MW CSP plant having this capability. I have no idea of the wind contribution, but it was said that during the earlier load-shedding this year there was little wind and the country was covered in cloud!?

For the coal-fired stations to improve, even to the reasonably modest target of 75% UCF, these aspects must dramatically improve. This would add 4 200 MW capacity to the Grid, and thus avoid the need for load shedding. Improvement to a an even better 80% would add 6 450 MW, equivalent to one and a half Medupi's!

This is really a much quicker and probably cheaper solution than designing and building new power stations, especially nuclear ones. And it is fairly "low-hanging" fruit, ie. easily attainable.

EFFECTIVE ISSUE MANAGEMENT

The second WANO pillar of Effective Plant Management is CAP (Corrective Action Program, known in Generation as Issue Management). It is underpinned by an effective system of identifying all the plant-related Issues (previously called Occurrences, or Incidents) and dealing with them effectively. But one of the technical problems that have been identified by Eskom's technical managers is the collapse of the Issue Management system at many power stations.

And so the plant problems are not being reported and effectively managed. Also the engineers do not seem to be accurately identifying Root causes, or developing Corrective Actions to effectively address them. Nor are the managers ensuring that CA's are properly and speedily implemented. Without these four vital steps in place, the plant problems are unlikely to be resolved, and plant performance will continue to deteriorate.

In 2005, I was on early pension after 32 years experience in and around Eskom's power stations. Having worked in Operating, Commissioning, Management, Engineering and Training functions, I was contracted by Generation Group to assist with, amongst other concerns, the problem of increasing numbers of Major plant incidents. I believed that the problem had its roots in the way the findings and recommendations of previous incidents were managed, and suggested a solution based on the Kendal system. This was adopted and the Occurrence Management Procedure was extensively revised to capture these aspects.

Lately it has emerged that these principles have become diluted, and are not properly implemented. So full attention must again be given to this, and with a system implemented to record all plant issues. These must be effectively evaluated and classified to identify the more serious ones issues requiring investigation and possible action. Investigators must be effectively trained in Information gathering, causal analysis and corrective action development. Lastly, Management must ensure that full attention is given to the timeous implementation of the actions requiring attention.

CONCLUSIONS

Plant Performance is directly linked to the attitude and competence of staff in the Operating, Maintenance and Engineering functions. The senior plant management must regard it as an important part of their own function, emphasised by assigning large portions of their Performance Appraisal factors to this component.

The Power Station Management should also have direct authority and responsibility for the Engineering department at their station, and ensure that the Engineering outputs are directly linked to meet the station problems and priorities.

The Engineering department must make plant performance their major output, and ensure that all Issues (Incidents) are fully captured and managed. They must have an adequate number of Issue investigators who are skilled in Causal analysis and derived actions, and ensure that these are fully and timeously implemented.

Plant availability performance improvement from 65 to 90% would add an extra 25% generating capacity to the National Grid, about 10 000 MW! Whilst this is probably not immediately attainable, even a modest 12% would add 5 000 MW, more than the new Medupi will be supplying. wn

November

Movers, shakers and history-makers

COMPILED BY I JANE BUISSON-STREET
FSAIEE I PMIITPSA I FMIITSPA

1 NOVEMBER

1887 Eleven years after the phone was invented, the first differentiation between day and night long distance rates went into effect, with most night rates being lower than day rates.

2 NOVEMBER

1920 Westinghouse Electric launches radio station KDKA ("The Voice of Pittsburgh"), - the world's first commercial radio station.

3 NOVEMBER

1507 In Florence, Italy, Leonardo da Vinci was commissioned to paint a portrait of Lisa del Gherardini that would become known as the "Mona Lisa." Her husband, Francesco del Giocondo, commissioned the work shortly after she had three teeth pulled and false teeth fitted.

4 NOVEMBER

1952 CBS News used a UNIVersal Automatic Computer (UNIVAC I) computer to predict the outcome of the 1952 presidential election after analysing only 5% of the tallied votes. The computer projected a victory for Eisenhower, but journalists, Charles Collingwood and Walter Cronkite, felt that the result was so unlikely based on the fact that the opinion polls consistently predicted a landslide victory for Stevenson so they postpone announcing the UNIVAC's results.

5 NOVEMBER

1906 Marie Curie is appointed as the first female lecturer at the Sorbonne University in Paris, France. In her inaugural lecture, Curie explained her theory on radioactivity.

6 NOVEMBER

1998 The third millionth domain name (lizzybee.com) was registered.

7 NOVEMBER

1911 Alan Archibald Campbell-Swinton, during his presidential address, suggested that high-definition television was possible with cathode ray tubes. The paper wasn't published until April 1924 when it appeared in Wireless World.

8 NOVEMBER

1895 Wilhelm Röntgen observes X-rays for the first time during an experiment at Würzburg University, Germany.

9 NOVEMBER

1921 Albert Einstein was awarded the Nobel Prize in Physics for his work on the photoelectric effect.

10 NOVEMBER

1882 Alexander Graham Bell was finally granted U.S. citizenship after his 2nd application.

11 NOVEMBER

1675 Gottfried Leibniz demonstrated integral calculus for the first time by finding the area under the graph of the y = f(x) function.

12 NOVEMBER

1901 The first Nobel Prize for Physics was awarded to Wilhelm Röentgen for the discovery of X-rays.

13 NOVEMBER - WORLD KINDNESS DAY

1928 Vladimir Zworykin, considered to be the "true inventor of television", was granted a patent for a colour television imaging tube that used cathode ray tubes and a screen composed of a mosaic of squares in the three primary colours.

14 NOVEMBER

1997 Disney's "Lion King" set a Broadway record of $2,700,000 daily sale.

15 NOVEMBER

1956 Elvis Presley's 1st film "Love Me Tender," premiered in New York City.

16 NOVEMBER

2014 Chocolate manufacturers stated that a cocoa-pod fungus, as well as dry weather, in cocoa-growing regions has created a shortage of cocoa that may increase in the future. Currently world chocolate demand already exceeds production capacity.
(This is a disaster!!! - ED)

17 NOVEMBER

1970 Douglas Engelbart received a patent for the first computer mouse known as a "X-Y Position Indicator for a Display System." It was a simple hollowed-out wooden block, with a single push button on top.

18 NOVEMBER

1993 South African political leaders approved the Interim Constitution, the fundamental law of South Africa from the first non-racial general election on 27 April 1994 until it was superseded by the final constitution on 4 February 1997.

19 NOVEMBER

2007 Amazon.com released its e-book reader, the Amazon Kindle, in the US. The device, developed by Lab126, featured a 6-inch (diagonal) 4-level greyscale display with E-Ink with sixteen shades of grey, 250MB of internal memory, and an SD card slot. The Kindle sold out in less than six hours and remained out of stock for another five months.

20 NOVEMBER

1906 Electrical engineer Greenleaf Whittier Pickard received a patent for the crystal detector (cat's whisker detector), a radio wave detector that was the central component in early radio receivers called crystal radios.

These were the most widely used radio receivers until about 1920 and continued to be used until World War 2. Pickard's patent application described the device as *"a means for receiving intelligence communicated by electric waves."*

21 NOVEMBER

1905 Albert Einstein published his paper, *"Does the Inertia of a Body Depend Upon Its Energy Content?,"* in the journal "Annalen der Physik." This paper revealed the relationship between energy and mass which leads to the mass-energy equivalence formula $E = MC^2$.

22 NOVEMBER

1904 The first direct current, electric motor to be patented in the US was issued to Mathias Pfatischer of Philadelphia, Pennsylvania. The "Variable Speed Motor" was designed to *"effect commutation without sparking, with a variable load as well as at variable speed and which is capable of rotation in either direction."*

23 NOVEMBER

1979 Pink Floyd's "The Wall" was released and 6 million copies were sold in 2 weeks.

24 NOVEMBER

1969 The Apollo 12 spacecraft splashed down safely in the Pacific Ocean, ending the second manned mission to the Moon.

25 NOVEMBER

1969 John Lennon returned his OBE in protest against the UK's support for Vietnam War.

26 NOVEMBER

1607 William Shakespeare's King Lear was published.

27 NOVEMBER

1895 Alfred Nobel signed his last will and testament at the Swedish-Norwegian Club in Paris. His estate was to be set aside for the purpose of establishing the Nobel Prize after his death.

28 NOVEMBER

1814 For the first time The Times newspaper in London was printed on automatic, steam-powered presses. Newspapers were now available to a mass audience.

29 NOVEMBER

1910 Ernest E. Sirrine of Chicago was awarded a patent for a system of traffic lights.

30 NOVEMBER

1944 HMS Vanguard, Britain's largest and last dreadnought battleship ran aground.

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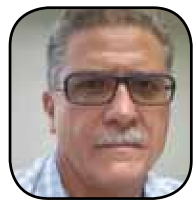

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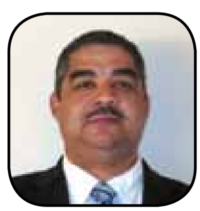

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