IMAges NZ
ISSUE TWO

The maths of steel

Mathematics is at the heart of converting the black ironsands of Maioro, south of Auckland, to a variety of sheet steel products. Jenny Rankine explains.

Nick Depree is developing a mathematical model of the annealing furnace at New Zealand Steel's Glenbrook mill, but he has never been inside it.

This is because the 150m-long, brick-lined tunnel operates at up to 1,100 degrees celsius, 24 hours a day. "It would have to be shut down for two weeks to be cool enough to walk through", says Depree.

Rolling steel from a slab to a strip makes it hard and brittle. Annealing relieves the internal stresses and softens the steel. Without this process, we wouldn't have corrugated steel roofs, steel roof tiles or steel garage doors. About 10% of the mill's steel production passes through this furnace.

The New Zealand Steel annealing furnace at Glenbrook towers three stories above the mill floor. Photo: Nick Depree. Below: A rare view inside, showing the heating elements above the rollers and the thermocouples in the centre.

To ensure a continuous flow, each new coil of sheet steel is welded to the end of the last one, and feeds through the furnace at a fast walking pace. The furnace, built in 1968, is old by world standards; it uses up to 4.6MW of radiant electric heating in its first 100 metres. The rest is for cooling, so that the steel emerges at the right temperature for its dip in the coating pots.

Most modern annealing furnaces are shorter, vertical and gas-fired, enabling them to change temperature much faster than the NZS furnace.

The computers running the furnace currently use a static state model, which does not include details of the furnace construction or the recently installed induction heater and gas jet cooler.

This model is accurate for about half the furnace's operating time. When the furnace is changing temperature or speed for different steel thicknesses or widths, supervisors rely on scheduling rules built up from years of experience. They don't always work; the coil may emerge with wavy edges or be too soft. As a result, around 100 tonnes of steel has to be discarded or downgraded each year.

This is where Nick Depree and NZIMA principal researcher Professor James Sneyd come in. With engineers Mark Taylor and John Chen, Sneyd is supervising Depree's three-year PhD project to build a dynamic model that will predict furnace and strip temperatures and metal properties during these changing states.

The equations are impossible to do by hand, so ▶2

Welcome

We hope you enjoy reading this second issue of *IMAges*, the colour bulletin of news and activities from the NZIMA.

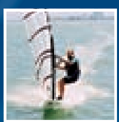
This is part of the NZIMA's new programme of outreach, intended to open a window on a selection of mathematical activities across New Zealand, and make these accessible to a wider community.

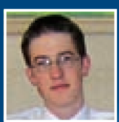
It will be complemented by our new MathsReach initiative - a collection of resources for students and teachers, to show what lies beyond the school curriculum in mathematics. This will be launched in late February and developed over time.

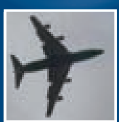
Find out more from www.nzima.org.

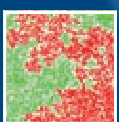
Marston Conder and Vaughan Jones
Co-Directors

INSIDE

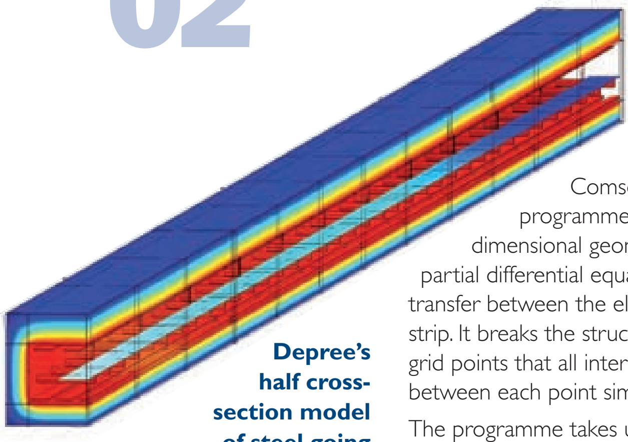








New Zealand Institute of Mathematics & its Applications



Depree's half cross-section model of steel going through the furnace.

◀ I Depree is using Comsol, a commercial modelling programme. "You build a three-dimensional geometry and plug into it all the partial differential equations that calculate the heat transfer between the elements, furnace and the strip. It breaks the structure into a mesh of 50,000 grid points that all interact, and solves the equations between each point simultaneously."

The programme takes up to four hours to solve the equations for the whole furnace. "I'm currently using a simplified half cross-section that can run in one and a half hours," says Depree. To be workable, the model has to be as simple as possible, while remaining accurate." Sneyd is advising on how to use maths to simplify the model. "It's not at all easy to do," he says.

Depree wants to get the model to within five degrees of the temperatures recorded by the furnace's 20 thermocouples. These wires of two different metals inside a metal pipe stick down through the furnace ceiling. The voltage difference where the wires connect measures the inside temperature; three pyrometers measure the radiation reflected off the steel.

"There is a lot of uncertainty in what these instruments are recording," says Depree. "I'm playing with heat transfer co-efficients as I fine-tune the model - conduction and radiation, which affect how the heat moves through the furnace and into the strip. Once I've got it to run acceptably, I'll need to run it many, many times to characterise different products and their dynamic properties." When it works, the model should cut steel wastage in half and reduce the furnace's power consumption by up to 10 percent.

NOTABLE MATHS PROBLEMS

RIEMANN HYPOTHESIS

The real part of any non-trivial zero of the Riemann zeta function is ½.

Simply: Some complex numbers - made up of ordinary numbers between 0 and 1, combined with a multiple of the square root of -1 - when fed into the zeta function produce the result zero. Do the infinity of such zeroes when graphed all lie on the same critical vertical line?

Discipline: Number theory. Hundreds of results in number theory now begin, "If the Riemann hypothesis is true, then..."

Originator: Georg Friedrich Bernhard Riemann, 1826-1866; German mathematician.

Incentive: $US1million, one of the seven Millennium Prize Problems of the USA-based Clay Mathematics Institute.

Attempted proofs: Supercomputer number-crunching has shown the hypothesis to be true for more than the first billion zeros. However, the hypothesis would be wrong if only one of the infinite results involved lies off the critical line. Several purported proofs have yet to be examined.

Is related to: Prime numbers. When the number of primes existing below a given number is plotted on a graph, it produces a smooth curve with small wiggles - the wiggles are the Riemann zeros. Riemann found that if the zeros do lie on the critical line then the maddeningly random distribution of prime numbers is predictable.

Unusual aspect: May be solved via similarities with quantum mechanics. French mathematician Alain Connes has constructed a quantum state space of infinite dimensions from the known prime numbers. In the first dimension, measurements are made with 2-adic geometry, which pulls together even numbers. The second dimension uses 3-adic geometry, the third 5-adic geometry and so on. Connes proved that the system has energy levels corresponding to all the Riemann zeros that lie on the vertical line, but he still has to prove that there are no zeros unaccounted for by these energy levels.

Could lead to: An efficient way of deciding whether a certain very large number is a prime. Mathematics based on the Riemann zeta function could predict the behaviour of chaotic quantum systems, such as the scattering of high energy levels in atoms and molecules, and the way in which sound and light waves bounce around.

NZIMA connection: Marcus du Sautoy, author of *The Music of the Primes*, which describes the hypothesis and its implications for a lay audience, will be visiting New Zealand as an NZIMA Maclaurin Fellow in February and March this year.

"The study of mathematics is apt to commence in disappointment ... we are told that by its aid the stars are weighed and the billion of molecules in a drop of water are counted. Yet, like the ghost of Hamlet's father, this great science eludes the efforts of our mental weapons to grasp it." *Alfred North Whitehead, 1861-1947.*

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Thinking around corners

By Jenny Rankine

It would be hard to find a less geeky mathematician than Vaughan Jones. The country's only Fields Medallist, the maths equivalent of the Nobel Prize, is famous for wearing a rugby jersey when he gave his plenary talk at the International Congress of Mathematicians that awarded the medal in Kyoto in 1990. And he kite boards the waves of San Francisco Bay in his spare time.

Jones is also famous for his informal and open style of working in an environment where competition can encourage mathematicians to keep ideas to themselves before they are published. Before winning the medal, Jones sent his new ideas to other mathematicians and encouraged their circulation. The medal citation says these letters became a rich source of ideas for many people.

Jones' discovery of the polynomial since named after him (an object that distinguishes between theoretical knots) was part of his development of an algebra that thinks around corners.

Anyone over 30 learnt algebra as a linear activity - A x B + C marching from left to right in a straight line to a conclusion. Jones thought laterally and imagined an algebra where A was upside down above B and C was off to the south-west. He has been working in the field of planar algebra ever since.

The field brings together ideas from operator theory, statistical mechanics and the more geometrical theory of knots and tangles. "It has created a structure for handling a lot of novel algebraic situations in a new way that is connected to physics and quantum field theory," he says.

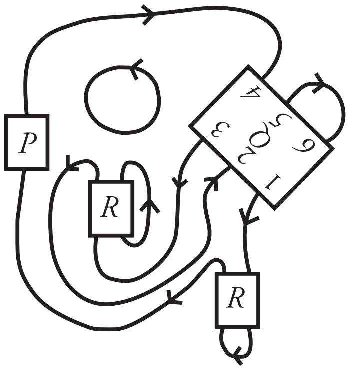
Physics is an old love for Jones, who started his PhD in the subject before switching to mathematics. "I've always done the kind of maths that's closely connected to physics." Planar algebra seems to be highly relevant to quantum computing, he says, although the role it will play is not yet clear.

Jones was born in Gisborne, went to school in Cambridge and Auckland and studied at the Universities of Auckland and Geneva. While he has been Professor of Mathematics at the University of California in Berkeley since 1985, he returns to New Zealand at least twice a year and has been a major stimulus for the growth of mathematics here.

He helped to found the New Zealand Mathematics Research Institute (NZMRI) in the early 1990s and is co-director of that as well as of the NZIMA. The NZMRI started an annual series of summer meetings in 1994, now sponsored by the NZIMA, bringing "the very best of world maths to mix with New Zealand mathematicians and students" at beautiful New Zealand beachside locations.

"They went from being rather primitive affairs to much more well-known and now we're turning people away," he says. "They've been a staggering success; you'd have real difficulty getting some of those people together anywhere else in the world." The Fields Medal was very useful to help get the meetings started, he says. He has been to every meeting, gaining a good overview of our mathematical expertise.

Maths in New Zealand "looks pretty healthy; we have some extremely good mathematicians here". New Zealand shines in fields such as numerical analysis, "providing numerical solutions for just about anything"; computer solutions; analysis; group theory; logic and computational complexity; mathematical biology and mathematical physics. "We have really world class leaders in those fields in New Zealand, constantly being invited to international conferences."



A labelled planar tangle

"A mathematician is a machine for turning coffee into theorems."
Paul Erdōs
1913 - 1996