WAIRAKEI - STILL GOING AFTER ALL THESE YEARS

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ABSTRACT

The development and evolution of the Wairakei steam winning, separators, multistage flash and pipelines has been well documented. The changes in the station's generating assets have been just as significant, but are relatively unheralded. From an experimental plant in the 1950s with an expected life of twenty years, Wairakei has evolved into a generation facility still reliably operating sixty years later. The nett result is a plant that has set the standard for longevity and load factor. The machines still in service have each done over 400,000 running hours. Many of the components are still original, a tribute to the conservative design. This paper documents some of the issues that have occurred on the station plant and the modifications made to overcome them.

1. THE STATION

1.1 Commissioning the New Plant

Wairakei Power Station first officially synchronised a machine to the grid, Generator 2, just after 3pm on Saturday, 15th November, 1958. At the time, New Zealand was under power restrictions so the extra generation was welcomed. Earlier that year, the organisation running power stations had changed from State Hydro-electric Department of Ministry of Works to the New Zealand Electricity Department, in part to reflect the change in the energy sources. Lore has it that Wairakei started before Atiamuri that day, but contemporary reports (Dominion) show that at the hydro station, the engineers did not wait for the Minister's official opening and started early that morning.

Over the next five years, another twelve machines were commissioned, with the last being Unit 13 in October 1963. The maker's plates on the later 30MW MP machines might say they were made in Manchester, but all units were built in the Rugby Works. Though the sum of the nameplate rating was 191.02MW (not the 192.6MW often quoted in literature or the 193.018MW in the OEM manuals), it was regarded as a 160MW baseload station by the designers, with the range manifolds allowing units to be brought in and out with the requirements of maintenance and outages (Haldane). This was in line with the philosophy of the hydros and other plant being built by Ministry of Works at the time, like the coal fired units at Meremere.

G2 was the first grid connected unit, but a small turbine had been running up in the borefield near the Circle Group of wells since March 1956. This provided electricity for the construction project. (Taupo Times, 1956). It was necessary because until 1958, there was no grid connection to the area, with many local properties including the hotel needing their own generators for power.

The commissioning of the station was the culmination of an extensive investigation into the technology that would be needed. At an early stage, two Ministry of Works engineers went to Italy in 1951, visiting Lardarello and several turbine factories, and talking to various officials, scientists and engineers. A major recommendation of the ensuing report was to use the geothermal steam directly in the turbines, rather than have heat exchangers and use of reboiled water with clean steam like the earlier Lardarello units were (Fisher). Metallurgical trials were then done at Wairakei using geothermal steam to determine suitable materials.

The contractual documents show that conservativism was critical. To quote Haldane "Security of supply was the prime consideration" Equipment of proven design was wanted throughout the plant. Metals that had known resistance to geothermal conditions were specified. Turbine blade tip speed was limited to reduce water drop erosion because the blades couldn't be hardened. Any copper had to be wrapped or treated.

Construction of the station started in 1956. A village for the construction workforce was one of the first activities. A year later, the first village for station workers was built where the binary plant now is (Figure 1). As the main road to Rotorua then went through the site, it would have been a busy place – even having its own police officer. A lot of thought went into what future development would occur. The original design allowed for the construction of B and C Stations, as well as raising of the river level by three metres when Aratiatia was built.

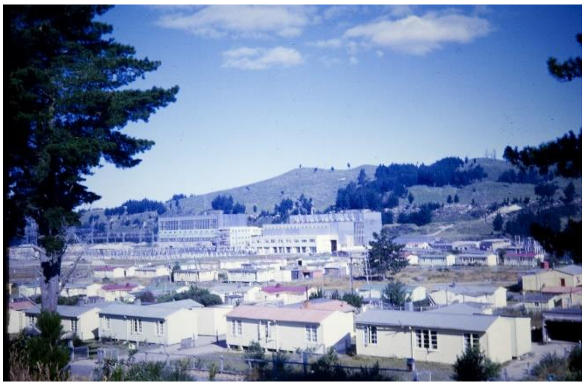

Figure 1: The station and original staff village

1.2 Early Operation

In the early years of operation, the plant was unreliable. There were numerous breakdowns and high maintenance costs as equipment was repaired or replaced. It got to the stage where the station control room had to ring the Minister to tell him of the failures so he could answer questions in Parliament about it (K Wilson, pers. comm). The situation was not helped by the very poor monitoring systems available. Only electrical information like voltages and currents came back to the control room (Figure 2). Everything else was done by an operator out on the floor, with information being recorded on chart recorders or manually in a log. There were high cycle fatigue failures in the pressure reducing valves, needed to pass the steam from one manifold to another if machines weren't available. As time went on, problems were addressed, better monitoring equipment became available and operation experience increased, the performance got better. The decision was also made to try to run all the units available, rather than having some in reserve standby. This allowed partially loaded units to have their output ramped up if a trip occurred, minimizing the load loss, but the generation overall was lower.

Figure 2: The original control room

1.3 The Golden Years

By the mid 60s, the plant reliability had got to a stage where the plant was providing genuine base load. In 1965, it produced over 12% of New Zealand's power. Xmas Day 1966, it was generating half the North Island's load (K Wilson, pers. comm.). There was still the issue with there not being enough steam to fully load the units. Steamfield changes are documented elsewhere (Thain 1984, Carey 2009) and are outside the scope of this paper. The HP inlet pressures were slid as the steamfield ran down. .Little other optimisation at station was done. During the 1970s, there was no significant work done on generating assets. Capital investment was restricted because of the major build programme for new power stations to meet the constantly growing demand. The decommissioning of the HP units (2, 3, 5 & 6) in the early 80s allowed some rationalization of the plant. The additional steam from new wells justified the major refurbishments which started and would continue for the next ten years, effectively a mid-life refit. This included replacing the IP rotors, the MPIP casings and uprating the instrumentation to do remote supervision and automated operation. The operations mode was changed from fixed operator attendance to one of a demanned station, centralised control room and roving operators. This allowed Ohaaki and then the other stations to be integrated in to operations with minimal disruption (Figure 3). G14 (4.5MW rating) was commissioned in 1996, increasing generation and replacing the pressure reducing valves bringing the ILP steam into station. New large diameter steam lines rationalised and improved the IP manifolds.

Together with the capital work, there was a greater emphasis on bringing plant inspection and asset management up to modern practices. The instrumentation and protection systems had major upratings. A greater emphasis was placed on NDT inspections and there were several reviews done on the plant. These all confirmed that there were no major limitations or restrictions on the plant life.

1.4 The Decline

A pipeline from the top of the Wairakei borefield over to Poihipi was commissioned in 2006. This allowed the generation there to be increased, but reduced Wairakei a little. Load, particularly from 2013 onwards when Te Mihi was commissioned, was backed off at the less efficient Wairakei to stay within the resource consent limits.

With the commissioning of Te Mihi, three A Station machines were decommissioned because of lack of steam. Others were partially loaded. However, changes to consent conditions and more steam from additional steamfield secondary flash separators allowed one of the LP turbines to be recommissioned.

Figure 3: Control room in 2018 – usually unmanned as station run from Control Centre

The problem starting to rear its head was compliance of old plant with modern standards. Wairakei was built to the codes relevant at the time of construction. These have changed dramatically. Existing equipment is generally grandfathered in, but if modifications are contemplated, the plant may have to be brought up to the new requirements. For much of the equipment and plant, this may not be practical or economic.

2. THE PLANT COMPONENTS

2.1 Turbine Casings

The turbine casings were a combination of cast iron and fabricated low carbon steel components. For the most part, there has been little or no erosion and no corrosion on the cast iron. However, where there is damage, it is very hard to repair. Ceramic fillers have been used extensively to keep the mating faces flat and square. The use of flexible sealing compounds on the halfjoints have stopped a lot of leakage and wash erosion problems (Figure 4).

The steel exhaust casings, particularly the IP sections, have had extensive erosion damage. Major weld repairs have had to be done most surveys –an example shown as Figure 5. These have generally been by overlay, though components like turning vanes and watershed plates are regularly replaced. Going to thicker turning vanes made of a harder steel has extended life without losing performance. Protective metal spray has not worked. There appears to be micro cracks forming through the spray during operation. That has allowed the metal loss in the underlying material to continue, and then allowing pieces of the sprayed coating to break off into the cavity as they are unsupported.

Stainless iron inner casings for the 30MW MP machines were retrofitted during the 90s to replace the badly eroded cast iron ones. Reverse engineering of the old ones was done, design modifications made and then they were manufactured in Dunedin. They have been very successful and are still in as-new condition.

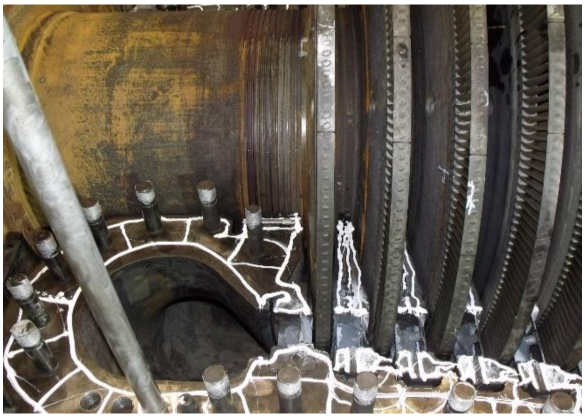

Figure 4: IP casing half-joint just before assembly showing sealing compound to stop leaks.

2.2 Turbine Rotors

The A Station rotors are monobloc while each B Station rotor has 15 discs shrunk onto a spindle. As long lead time items, there was a spare rotor for each type of turbine as a rotable spare.

By the 90s, the LP rotors steam gland sections were in very poor condition because the control system wasn't up to the task. This has since been rectified by getting new gland segments made and fitting better valves. The gland castellations have been restored by shrinking on sleeves and re-machining them to the original dimensions. This was possible because the coupling was shrunk and keyed on, rather than one piece like modern practice.

Figure 5: Replacing turning vanes in MPLP casing

The front face of the first LP disc on the MP rotors has suffered very severe water droplet erosion. This was from a very poor interstage seal setup that was there since installation. When the seals were replaced, station staff took the opportunity to redesign the seal, reducing the flow through it. The erosion rate has been effectively stopped by this change.

The MP rotor design is prone to cracking in the highly stressed keyways that secure the discs to the shaft. These can lead to catastrophic failure. NDT experts have developed techniques that allow comprehensive ultrasonic inspection of keyways. This has detected a number of indications, including some slowly growing hydrogen cracking. These are regularly monitored. The plant operating procedures were also changed to minimise the stresses.

2.3 Turbine Blading

The IP turbine blade failures are well covered elsewhere (Thain 1984, Thain 2009). They started six months after commissioning and were never sorted out until the rotors were replaced in the late 80s. There were two positives that came out of the problem; staff had very good skills with blading work, and senior management saw the benefits of critical spares. Having a spare rotor for each machine type has been a major factor in keeping the high unit availability.

The last five stages of the MP blades have been replaced after about 200,000 operating hours. LP3 to LP5 had cracking occurring in the lacing tube hole. Figure 6 shows one of these failures. LP6 & LP7 had leading edge erosion – at worst, about 30mm from a 100mm wide last stage blade. There was an early failure of the banding on the Stage 7 blades from poor tenon design. This was fixed by arc welding the banding onto the blade, then doing the heat treatment in a molten lead bath. This solution worked. It is still done nowadays on newly installed blades, but using TIG to minimise heat input, and flexible ceramic heat pads do the heat treatment.

The LP turbines have had their last two stages of blades replaced every 100-160,000 hours because of leading edge erosion. The first two stages of blades were replaced because of aerofoil cracking. This has been stopped by going to long run banding, simply welding up the gap between blade packets.

The new IP turbines blade tenons were severely eroded by debris coming down to station from the commissioning of dry steam wells in the 90s. This was remedied by welding up the tenons' leading edge with hardfacing, then doing a full heat treatment of the rotor.

Figure 6: Blading failure and subsequent repair to get back in service till rotor can be rebladed. Blade on opposite side was cropped to keep it in balance.

There are also in-service blade failures, particularly on the LP turbines. The failures have mainly been when the banding pulls off the tenon. Station staff got very good at doing fast repairs to allow the machine to continue running until the next overhaul and rotor replacement. 44 hours was the record from vibration trip until return to service, but nowadays it typically is a more leisurely five days.

2.4 Generators

The generators were built to standard practices of the time and had little in the way of added protection against H2S. There have been no problems with the stator or rotor windings. Activated charcoal air filtration on the make-up air was added in the 90s. This markedly reduced the wear on the carbon slip ring brushes and copper exciter commutator, allowing extended intervals between brushgear replacement outages. Nowadays, the timing is around 26 weeks for the A station machines and 42 weeks for B station. This timing is fortuitous, as it allows other maintenance and calibration work that would normally need a dedicated outage to be done.

The early voltage regulation system was by thyratron valves. These were not reliable and there were many losses of excitation. To minimise the risk of damage, the generator rotors were built with a heavy segmented copper amortissuer under each ferritic endring. Figure 7 shows this. These did a very good job of stopping arc damage in the shrink area of the ring and rotors during pole slip and phase inbalance incidents. In the late 80s, a programme was started to inspect all the rotor endrings in line with best practice. Most were found to have some arc pits from historic asynchronous motoring, pole slip and cracks forming in the rough machining around the bayonet teeth. For the most part, these were able to be dressed out. Replacement rings were fitted where the damage was beyond recoverable limits. The blanks were forged in Europe, then machined and fitted locally. The rings are now inspected every second survey.

2.5 Turbine Diaphragms

Turbine diaphragms were also components where there was a complete set of rotable spares. This meant repairs or refurbishment can be done outside the overhaul outage window.

Figure 7: 30MW generator rotor being worked on during endring inspection. Segmented ammortisseur and original mica insulation visible.

The diaphragms are cast iron with machined 410 stainless cast-in vanes. There are no embedded tip seals or castellations. The interstage seals are spring-loaded segments made of a stainless iron. The cast iron was very susceptible to both water erosion and handling damage. For some damage, block repairs have been done. The damaged area is milled out, a shaped steel block fitted, attached with screws, and then the gaps covered with ceramic filler. On the half-joints, the blocks or plates are typically stainless steel. The flatness, particularly on the sealing and halfjoint faces, is addressed by ceramic filler and a lot of care to ensure minimal gaps. When finally assembled, flexible sealing compounds are used (Figure 4).

The wash damage on the trailing rings was initially addressed by retrofitting stainless steel inserts. These then had nickel cover welds. Modern practice has been to apply protective metal spray on the eroded surfaces. This has managed to halt further erosion (Figure 8). The tapped lift eye holes have been replaced by stainless steel inserts. These give a lot more security during crane lifts.

There has been trailing edge cracking of vanes, particularly on the larger sizes. Weld repairs on these are done with the nickel based rods. Where the crack is close to a port wall, a block repair is done, and the weld attaches the vane to the block.

2.6 Turbine/ Generator Bearings

The main bearings are conservatively designed, low surface pressure white metal. Because of rapid bearing wear from the stop/ starts and hogging rotors, jacking oil and barring gear were fitted by the turbine manufacturers to the MPs between original design and commissioning. Bearing damage did not occur on those machines, with most of the main bearings on them still being original. The A station machines continued to have problems until station staff designed and installed a jacking oil system to them in the late 90s. After that, bearing wear stopped and maintenance work such as alignments can be done faster.

Figure 8: Machining a diaphragm after repairs and metalspray to ensure correct clearances are maintained.

2.7 Oil Pumps

The original design was for a turbine driven main oil pump. AC and DC oil pumps, and on the back pressure machines, a steam driven auxiliary oil pump. This was to allow a black start. The steam driven pumps were removed early on. This was because Aratiatia had black start capability and the steam leaked into the turbine oil. The gears in the main oil pumps have worn slowly, but the shafts are more prone to wear. This wear was reduced by changing the material of the white metal bearings they run in. The worm and bronze wormwheel driving the main oil pump need regular replacement. It is the major cause of the noise at the front end of the 11MW machines. Tooth pressure angle and design has been changed without apparent benefit to the wear rate. On the MP main oil pumps, the only components that have needed replacement are the white metal bushes that the gears run in. The motor driven oil pumps have been very reliable.

2.8 Steam Pipework and Manifolds

All the steam pipework inside the station was relatively thin wall carbon steel plate, commensurate with the low pressure present. This made them very susceptible to water droplet erosion, particularly downstream of the IP turbine exhausts; the exhaust legs, LP manifold, in-line Howden separators and LP inlet legs. As well as the direct impingement damage, particularly on the turning vanes in the exhaust legs and Howdens, there was ditching occurring on the seam welds.

Repair continues to be an ongoing maintenance activity. For minor damage, this is just overlay weld repair, but full wall patch replacement is done on the larger areas like in Figure 9. Historically, stainless steel overlay or ceramic coatings were used, but it is now done using just parent metal. The Howdens and legs were replaced in the 90s mid-life refit.

The pressure protection is accomplished by safety valves on the manifolds. These were high maintenance items and spares hard to obtain. They have been replaced by bursting discs, apart from those for the LP manifold on the roof of A Station. These remaining valves are overhauled and tested in-situ.

Figure 9: Full wall replacement and overlay weld repairs in LP manifold.

2.9 Condensers

The condensers were made of carbon steel which had a resin or sprayed aluminium coating applied. In the LP condensers, some components were cast iron. In the MP condensers, the drip trays were 400 series stainless iron and many of the baffles were made of 316L stainless steel. These were uncoated. The wall coating, while good, was subject to erosion from the pumice entrained in the water. Once the coating had failed, the underlying material rapidly corroded. Weld repairs were difficult as coating had to be replaced in-situ. In the 80s, the coating was replaced with two-pot epoxies. These have reduced the maintenance, but regular weld repairs and recoating continue to have to be done as the pumice still does damage. The stainless components are both erosion and corrosion resistant. However, they are prone to fatigue cracking from vibration caused by water impact. Rubber mounting the plates helped reduce the failure rate, but regular weld repairs or replacement are still needed.

2.10 NCG (Non-Condensable Gases) Removal

The original high speed gas exhausters to remove NCGs from the condensers were a total failure. Haldane admits that they weren't a proven design and were very unreliable. They were specified as they were about 4 times the efficiency of the ejectors, but based on the extraction fans used for steel furnaces. The 15,000 rpm motors not only had built up impellors shafts without a method of balancing, they were speed controlled by a salt water bath and supplied from a 750kW 250Hz frequency converter. It took several years and many minor modifications to get any form of reliability from them, but they were never dependable.

The MP units were never fitted with mechanical exhausters, but originally had three trains of two stage steam ejectors. These have now been replaced by an ejector and liquid ring vacuum pump (LRVP) train which improved the vacuum, hence output. They also consumed less steam, reducing parasitic losses.

The exhausters on the LPs were replaced, first by some of the MP ejectors which were very inefficient, then in the 90s by purpose built 3 stage ejectors. These improved the output of the machines by over 10% just because of the better vacuums. They were also significantly lower maintenance, being wholly 316L, rather than internally epoxy coated carbon steel.

Sulphur deposition, and associated bacterial corrosion under the deposits in the system has continued to be an operational problem. Vacuum deterioration from the partial blockages have necessitated outages to clean the plant, usually by waterblasting. The aftercoolers and associated pipework are those most prone to clogging. Routines put in place to do the cleaning during planned outages have been able to manage the situation to a nearly acceptable level.

2.11 Turbine Governing System

The machines in A Station were not designed to run at part load. To compound the problem, the flyweight governors had a very low droop, about 1%, so they were very susceptible to load variation when the grid frequency varied. This caused large fluctuations in manifold pressures. However, they weren't responsive to any overfrequency when at full load, in contravention of grid rules. The situation was resolved by station engineering adjusting them to a more manageable 5% droop. However, annual overspeed tests are still done by levering a piece of wood under the control arm.

The governor valves on the IP turbines had undersized actuators. This meant they were prone to sticking when the machine went through half load and the flow regime in the double beat valves changed. Because they were built into the valve body, and driven by the machine's control oil, they were not able to be uprated. The solution has been to avoid operating about that load. When it was necessary, the auxiliary oil pump was started to boost the actuating pressure, allowing the actuator to work better.

2.12 Cooling Water System

The Waikato River water used in the direct contact condensers is only coarsely filtered before use. The screens on the pump intakes have 100mm wide slots, and no secondary screens so there is no protection when they are pulled for cleaning. The debris is mainly weed from Taupo harbour and water logged branches. The secondary screens on each machine were drum filters with 6mm diameter holes in the drum plates. These originally clogged from pumice that was in the water. The plates had been drilled then rolled. The holes were then taper reamed from inside the drum to get them to clear more easily. When replacement plates were needed, station staff had an automatic drilling machine built that could drill tapered holes from the inside of a curved plate. This was effective, but occasional forced outages still occurred when the weed at the harbour was harvested, or there was very heavy rain. The drilled plates on the MP units have now been replaced by tapered wedges to try to reduce screen blockages.

The CW nozzles on the LP turbine condensers are prone to blockages from the weed that gets through the plates. Nozzle replacement for these isn't feasible because of their design. The neoprene nozzles (silicone rubber in places subject to steam wash) on the MPs are self-cleaning since a redesign removed the central core.

Where cleaner water is required, like seal water for LRVPs, tertiary filters with mesh screens or discs have been installed. Even with automatic cleaning and backflushes, these are still prone to blockages from the fine pumice. Staffing levels are such that operators often aren't available to clean filters. Usual workaround is to switch back to the secondary system until the cleaning can be done.

The concrete in the CW discharge culvert has needed extensive repairs over the years from corrosion damage cause by the NCGs and water. In many places, the rebar was exposed. It has been given urethane coating in the worst areas. This has limited further deterioration.

Consent limitations necessitated the building of the bioreactor. This was built in the old C Station (which was never built past the earthworks) pit. It replaced a lot of the worst damaged sections of the culvert. The plant has been a success, allowing continued operation at full load.

2.13 Instrumentation

This has been the area of biggest change. Whereas originally, it was only a few analogue gauges at the front of the turbine, it is now a comprehensive set of digital transmitters connected by fibre optic link to the control system. Even the failsafe pressure switches are being replaced by continuously monitored transmitters. Some of the changes have been brought about for legislative reasons, but most are trying to match best practice. Together with the instrumentation, a comprehensive calibration and assurance programme is followed.

The data from this instrumentation, being stored in a historian system, has allowed comprehensive trends and quite detailed fault analysis to be done. This has proved very useful in investigations into machine trips. Knowing exactly what the initiator was, and what was the consequential cascade, allows faults to be rectified and plant returned to service faster. There are downsides – false positives are now a major cause of trips. Minimising these is a big work component for the C&I staff.

The backpressure turbines originally had 7 gauges in the control room, another 8 on the turbine gauge board (TGB), 18 points on a chart recorder and the annunciator panel giving the status of another 9. Now, there are 63 points where status or data is logged by the historian system and another 8 on the gauge board. The change to the TGBs is shown in Figure 10. For the MP machines, there are about 150 points. Even now, there are some things that aren't monitored, such as valve position. However, on baseload plant, it would be hard to find economic justification for retrofitting such equipment unless there was a legislative compliance requirement.

The best illustration of the effect of the changes is turbine vibration monitoring. As built, there was nothing other than an operator's senses. The turbine blade failures were often identified by the shaking causing lightbulb filaments to fail in the nearby control room! (K Wilson, pers. comm.) Pedestal accelerometers operating mercury tilt switches to trip the machines were then introduced. This was supplemented by a portable instrument allowing in-service monitoring. Then, proximity probes were retrofitted in the bearings, allowing journal-to-housing movement to be measured. This system is now on its second iteration, with datalogging, failsafe monitoring and the addition of voting speed sensors for electronic overspeed protection.

The wiring for instrumentation has needed special protection from corrosion. Original wiring, including pyrotenic cables, rapidly failed. Tinned copper and thermal stripping of the shield has been proven as the most effective method. Circuit boards needed to be tropicalised or kept in a filtered environment. The station telephones had special gas resistant models with platinum and gold contacts.

3. MAINTENANCE MANAGEMENT

3.1 Overhauls and Surveys

The overhauls were originally on three yearly intervals for the B Station machines and two yearly for the A station LPs. The nominal interval for the IP turbines was two years, but the regular blade failure often meant they did not last this long.

In the 90s, the inspection interval was extended to five years as the maintenance history had shown that the reliability for extended interval was there. The overhauls were contracted out. The MP machine were brought back to 4 years for a period to tie in with other maintenance. Once those issues were addressed, they have gone back to the longer interval. The surveys were also brought back to being managed in-house to keep better control on costs and timing.

Work practices have changed over the years, often to shorten the outage time. A comprehensive set of jigs and fittings have been assembled to aid this. The turning frame for the MPLP casing (Figure 11) allowed the job of diaphragm removal and refitting to be done faster yet with less risk. The complete replacement of grit blasting by high pressure waterblasting reduced the risks of contamination and metal removal. Even using slings rather than wire strops for lifting made the lifts easier.

The maintenance and overhaul programme is run in-house. The OEM of the units is not used for anything other than historical information. With the changes made to companies by amalgamations and the passage of time, staff at the station know a lot more about the plant than the manufacturer does. This extends to major overhauls and even refurbishments. Other than specialist skills like NDT or generator inspections, station staff run and provide engineering advice for the surveys, with contractors used to supplement the maintenance staff.

Figure 10: The original analogue TGB at top with current digital vesion below

This has been helped by comprehensive spares kept on site, especially those for long lead time articles. This included rotable items like diaphragms and valves which allowed refurbishment outside the outage window. Many were initially ordered at the time of construction. They have been supplemented by items found to be subject to wear or breakage. Site workshops are comprehensive and allow many tasks to be done on-site with the available tooling. This does allow faster turnaround, shortening outages. The big lathe has proved invaluable for the rotor refurbishments as well as defect repair and NDT on the rotors.

Figure 11: Rolling the MPLP top casing using two cranes and special turning frame.

3.2 Documentation and Technical Information

Wairakei was issued with a comprehensive set of drawings and manuals as part of the construction contract. This included many of the component manufacturing drawings, even including items like rotors and casings. As the station had a drawing office for much of its life, the records were added to as plant was maintained and equipment reverse engineered. Modifications and design changes were incorporated into the system. Most of the drawings have now been digitised, but staff still prefer the hard copies in their folders that take up a wall of the library.

Almost all work is covered by procedures and checksheets, which are controlled documents. The information in them is from a variety of sources and they are regularly reviewed. In keeping with most modern practices, they have embedded drawings and colour pictures where appropriate. The checksheets generally have acceptance limits on the dimensions to be measured. This has allowed the work party to know what components need further work or replacement. The use of these has both reduced the error rate of people doing the task, and allowed comprehensive, informative records to be kept.

4. OPERATIONS SUMMARY

Before 2011, the lifetime operating hours of the plant was over 85% - for the MPs, it was 90%. This includes all the early breakdowns, steam shortfall and the refurbishments. In the period 1989 to 2009, when the plant was able to be near full loaded, availability was 95% and forced outage factor of less than 1%. Load factor was nearly 94%. Over the thirty year period starting 1984, the load factor was 92%. This was for plant twenty five years old at the start of the interval – normally on the upslope of the bathtub curve.

Since the commissioning of the Poihipi steam line and Te Mihi, Wairakei station generation has dropped. This has been compounded by consent constraints where machines are on reserve standby, idled or only partially loaded because of mass take limitations. The uprating of safety requirements have extended the outage times. Even with these changes, annual availability is still over 90%. Figure 12 shows the record since commissioning.

As would be expected with the high availability on baseload plant, the actual operating hours is very high. All of the machines still generating have done over 400,000 hours. Rather than being the “grandfather’s axe”, most of the components are still those originally installed. Up until the end of 2017, Wairakei has generated nearly 68TWh – worth over $5B at current electricity prices.

5. DISCUSSION

The words in the author’s 2003 report seem as relevant today as when they were written:

“Much has been written about Wairakei. It has captured the imagination of many people not just because of its novelty, (photographs of the steamfield are to be found in a wide variety of publications) but for its acknowledged success as a reliable power generator for New Zealand. It would seem fitting after the years of generation at Wairakei to pay tribute to the many people from all levels that have contributed to its success over the years and played no small part in achieving its enviable reputation. The geothermal stations that continue to have been built in New Zealand, all of which have been smaller than Wairakei, is also proof of the continuing faith in geothermal energy as a reliable supplier of the country's power".

The results speak for themselves – The reliability and load factor from the Wairakei power plant has been world class generation. This was from a combination of both the initial conservative design and modifications made over the years by station staff. That proven performance and good reputation is a major reason why geothermal is regarded as a reliable generation source around the world.

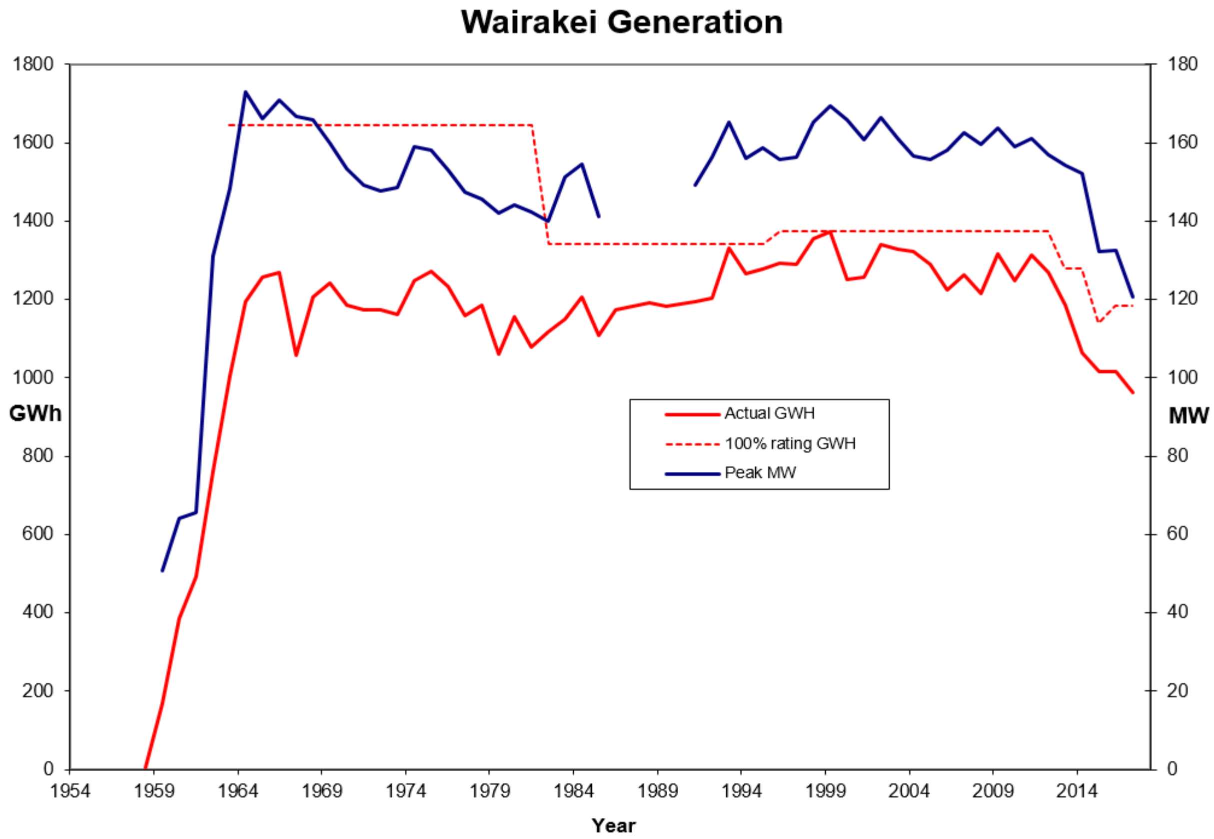

Figure 12: The generation and peak output of Wairakei on a yearly basis since commissioning. Average load factor since 1963 is 84%

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