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Wairakei Power Station – New Zealand Plant Modifications Arising from Operational Deficiencies, Technology Advances and Life Extension Studies

Chris Morris[1] Brian Carey[2]

[1] Generation Engineer, Contact Energy Limited, Wairakei, Private Bag 2001, Taupo, New Zealand

[2] Geothermal Section Manager, GNS Science, Wairakei Research Centre, Private Bag 2000, Taupo, New Zealand,

Chris.Morris@contact-energy.co.nz, B.Carey@gns.cri.nz

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ABSTRACT

The Wairakei Geothermal Power Station has had a remarkable generation history since machine commissioning through the period 1958 to 1963. The paper discusses some of the plant design constraints, the early reputation of the plant and learning experiences from over 50 years of operation. Plant deficiencies have been identified and analysed, plant maintenance processes have changed, life extension studies have been completed and technology advances have occurred through the decades. Modifications to the plant and maintenance practices have been made enabling the Wairakei steam turbine plant to achieve high availability, low forced outage factors, high plant load factors and an enviable 50 years of production service from the original plant. The paper discusses selected aspects and modifications to the plant that have contributed to 50 years of outstanding service from the Wairakei Geothermal Power Station.

1. INTRODUCTION

The paper identifies plant design constraints that limited what was able to be installed and provides some commentary on the plant redesigns that occurred before commissioning. During the early years of operation the plant gained a reputation for being unreliable regularly suffering forced outages. The issue of reliability was politically sensitive and communication was required to inform the Minister of Electricity and other government officials every time a machine trip occurred during critical times. The paper discusses some of the focused operational and maintenance activity that dramatically changed this reputation. Various aspects of the station plant are discussed, including turbine blading, diaphragms, midlife machine assessments, Intermediate Pressure (IP) machine refurbishment, Mixed Pressure (MP) inner casing replacement, electrical equipment, instrumentation, machine overhauls and plant performance.

2. KNOWLEDGE, SIZE, WEIGHT AND OTHER CONSTRAINTS

The power plant design was constrained by the available geothermal knowledge at the time particularly because there was little or no experience with wet geothermal steam generation. This was alleviated to some extent by information gained by NZ engineers who visited Larderello, first with the army during World War II and then as part of a fact finding tour in 1948, pioneering metallurgical studies undertaken in the early 1950's (Marshall (1955)) and the adoption of conservative engineering practice. The designers had significant restrictions on component dimensions and weight imposed by the then existing rail and road system. The components had to be shipped to Auckland, off loaded, transported by rail to Tokoroa and then by road to Wairakei. Particular constraints were manifest in the Auckland rail tunnels (Load height limitations of 8.5', with 45^o top chamfers and width limitation of 8') and the Atiamuri road bridge (Package weight limitation of 50 tons).

The power station went through at least 4 major redesigns before first machine commissioning in 1958. Initially the project was conceived as a dual power (47-MW) and heavy water (6 t/yr) distillation plant but by the end of 1955 the heavy water distillation plant had been abandoned and the project proceeded as a power only facility (Bolton, 2009 p25). Additional background to the reworked designs, including removal of the heavy water production plant from the process and the changing MW capacity estimates of the steamfield resource as drilling investigations progressed are discussed in Thain and Stacey (1984).

The design was for a baseload station with redundancy of critical auxiliary plant. As with most stations at the time, Wairakei had both black start and islanding capability. The designers also had to take into account that the Waikato River from which the cooling water was taken and returned would be raised by about 3m by the downstream Aratiatia hydro development in 1964, soon after the Wairakei station commissioning was completed.

The MP machines (30MW) were designed so that they would be topped up with additional superheated steam part way along the steam path. This was seeking to reduce the expected moisture damage to the turbine blading from the wet steam operation particularly from the moisture formation in the steam path in the sub atmospheric low pressure stages. 60MW machines were considered for B Station but the component dimension restrictions discussed above meant that the generator stators would have had to be assembled on site. Hydrogen cooling of the generators was not seriously considered at the time because of the additional complexity.

Taupo and Wairakei were small isolated settlements and infrastructure had to be built as the station was constructed. Reticulated electricity was not available in the area when the construction started and electricity for the construction site was provided by three steam engines in the steamfield and by diesel generators. The steam driven machines were: an old vertical Curtis turbine from Harris Street Power Station Wellington (Figure 1), a 500 kW triple expansion steam engine from the Christchurch tramways and a small Belliss and Morcom piston engine (Figure 2). Geothermal electricity generation effectively commenced about two years ahead of the official 15th November 1958 synchronisation ceremony of the Wairakei Power Plant.

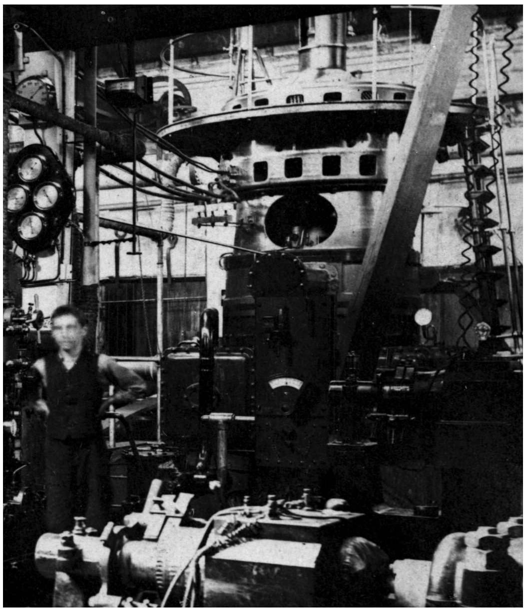

Figure 1 - Vertical Curtis Turbine in Harris Street Power Station Wellington about 1907. Photo from the Energy Library photo catalogue. Also in a photo in Martin (1991) p62.

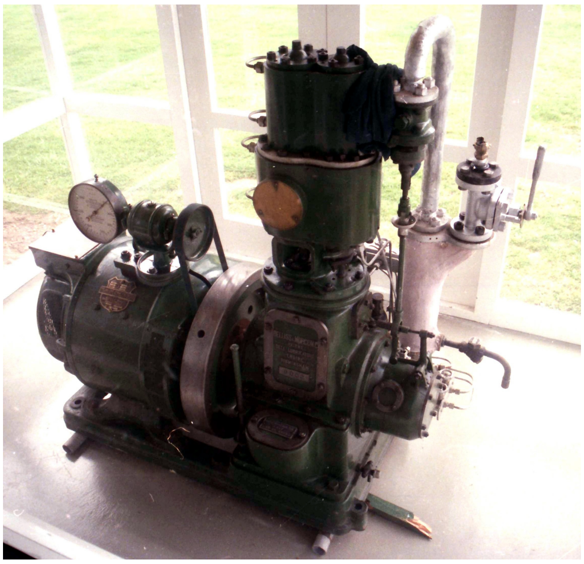

Figure 2 - Photograph of Belliss and Morcom steam powered piston engine generator (16 BHP @ 700 rpm) used in the steamfield carpenters yard (Murphy's yard) during construction.

3. UNRELIABLE WHITE ELEPHANT

Between the official synchronisation ceremony and October 1963 the remaining 12 machines were brought on line. Figure 3 is a mid 1962 schematic machine layout. The machine arrangements at completion of commissioning are discussed in more detail in Thain and Carey (2009).

The machine commissioning dates are identified in Carey (2000) p 3149. Through the period 1958 to 1963 the machines developed a not undeserved reputation for being unreliable with numerous forced outages. Sequential relays were not installed so while the operators knew which machine had tripped they did know what had caused the trip. It was guess work as to what had forced a unit off line. That often meant that if the assessment was not correct a repeat trip would occur. The A station rotary gas exhausters were unreliable and had no redundancy. During the early years, Wairakei was on a transmission spur line so lightning strikes added to the forced outage events. At times the grid experienced significant frequency excursions as there was little or no grid spinning reserve causing units to trip either from voltage regulation or turbine control oil pressure fluctuation An additional problem existed before the level of the Waikato River in the vicinity of Wairakei was raised for the Aratiatia Hydro power station. A machine trip could result in a cooling water pump losing its prime. Reinstating the pump to service required an operator to connect up a vacuum pump to lift water up into the pump housing before a restart could be attempted.

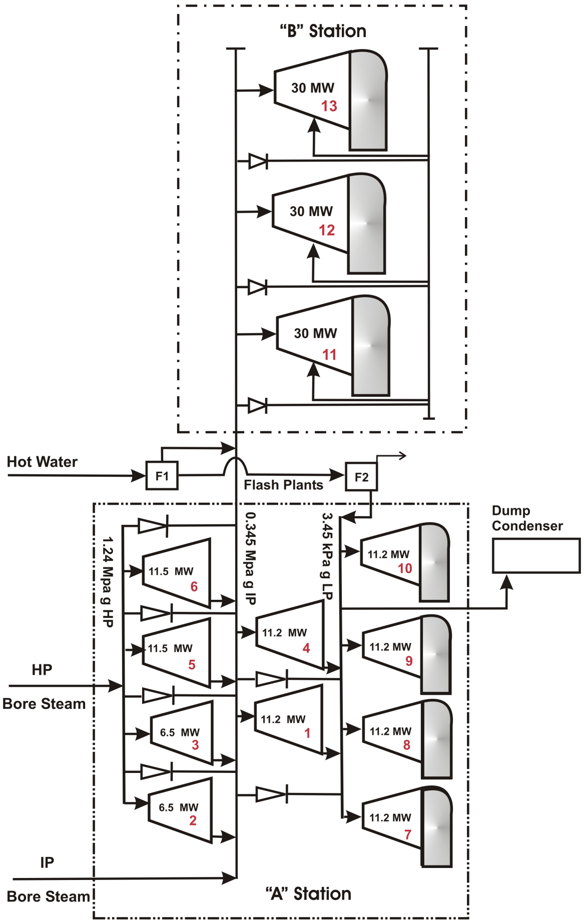

Figure 3 - Station configuration prior to decommissioning the station hot water flash plant in mid 1962.

The machine type and number identification is detailed in the table below.

Type	Units	MWe
High Pressure (HP)	G2, G3	6.5
High Pressure (HP)	G5, G6	11.5
Intermediate Pressure (IP)	G1, G4	11.2
Low Pressure (LP)	G7, G8, G9, G10	11.2
Mixed Pressure (MP)	G11, G12, G13	30

The reliability issue became sensitive to the point that a special telephone was installed enabling the Operations Shift Supervisor to inform government officials of the reasons for every trip during critical times over the winter months when a trip often caused power outages to parts of the North Island grid. If Parliament was sitting, the Minister of Electricity also had to be rung, so he could answer any questions in the House of Parliament. Questions were asked about why money had been invested in such a white elephant, though it is likely that there was more than a hint of theatrical politics in this.

4. IMPROVING WITH EXPERIENCE

As experience was gained with operating the machines and teething issues were sorted out, a number of changes were identified that have contributed to improved availability and reliability. A benefit of the station's isolation was the comprehensive drawing records and the level of rotable spares, including a spare rotor and diaphragms for each machine type and spare generator transformers purchased as part of the original procurement contracts. These spares enabled reasonably rapid return to service after failure and facilitated machine operation while modifications or repairs were made to failed components. A (Broadbent) turbine rectification lathe large enough to machine a 30 MWe MP rotor (Figure 4) was also procured and installed in the B Station as part of the original supply contract in order to facilitate repairs.

Figure 4 - Turbine rectification lathe. 2009 Machining off blade row LP7, of an MP machine rotor at about 3rpm, in preparation for reblading. Lathe operator is behind the rotor. Rag on rotor signals to assistant when to increment the tool post.

Rapid bearing wear had been experienced on the units in A Station from the numerous outages that had occurred in the early years of operation. Jacking oil and barring gear were retrofitted to the MP machines between the time of design and manufacture in England and their installation at Wairakei. These were installed in order to reduce bearing wear and rundown / run up shaft hogging on the MP machines.

There was accelerated exciter brush wear and brushgear replacement outages had to be scheduled every month. An issue that resulted from the frequent brushgear maintenance was that carbon particles were spread throughout the generator windings. These had to be cleaned off with white spirits to raise the insulation resistance. The manufacturer expressed concerned about cleaning lowering the service life of the windings. In order to reduce the carbon contamination in the generator, the exciter air supply was separated from the generator air supply.

G2 and G3 (6.5 MW HP machines) never performed to rating, initially only being able to produce 6 MW. Webs in the inlet belt were thinned and steam chest nozzle changes enabled generation at 6.3 MW. By the time that these changes were made the steamfield High Pressure (HP) operating pressures were being reduced (Carey and Thain 2009 p57) curtailing any further work.

When the pressure reducing valves around the HP machines (refer Figure 3) were in use there was significant noise in A station. Operators did all they could to avoid the use of these valves. High vibration levels caused metal fatigue, necessitating changes to some components. Fatigue related modifications included changes made to the Intermediate Pressure (IP) turbine diaphragms seeking to reduce rotor blade failures. This is discussed below in section 5.1.

Some automated equipment didn't work adequately and valves were reverted to manual control. The MP machine pressure reducing valves between the IP and LP steam manifolds shook their controllers and position indicators to destruction. With the addition of a safety relief system they could be run on fixed settings.

As constructed the station steamline isolation valves (valve 1) were located inside in the station pipe bay. Following a gasket failure that resulted in the inability to shut the valves because of the volume of steam filling the station the valves were relocated outside to the Anchor 1 position. Wells had to be taken off line in the steamfield to shut the station down at the time of the gasket failure.

The four motor driven, high speed, ten stage gas exhausters on the three Low Pressure (LP) machines (G7, G8, G9) were both inefficient (in terms of vacuum) and unreliable. The exhauster starting procedure needed considerable modification to get the as supplied equipment to work. This equipment was never up to the service duty. More detail is in Thain and Stacey (1984) and Carey and Thain (2009). The exhausters were phased out of service being replaced by two stage steam jet ejectors. These came from unused units in B Station as well as additional units supplied from the original equipment manufacturer. This replacement was completed by 1970. In the late 1980s, the ejectors on all the LP machines were replaced by three trains of three stage ejectors manufactured by Nash-Kinema. These units improved the vacuum performance with reduced steam consumption. The multiple trains (3 x 35%) were to allow for variable gas content from the wells in service and reduced machine load operation.

Corrosion, pitting and seizing of valve spindles was an issue until PTFE packing was used. Some shaft materials were changed to stainless iron. Brass or bronze components such as sliding threaded nuts or bushes could not be used where they were exposed to H_2S gas because of corrosion. Valves were prone to jam so more force on larger handwheels was used to work stuck valves. In one case, the exhaust valve of G5 had the 60mm shaft stretched to necking and the threads stripped off by over-enthusiastic use of wheel keys. Operation of some butterfly valves required two people. Gearbox failure resulted in these valves being replaced with wedgegate valves. Condenser nozzles were changed to designs less liable to clog with the river weed that passed through the strainers. The steam driven oil pumps for black starts were decommissioned because they weren't needed having not been used. The isolation valves didn't seal adequately allowing steam to condense into the turbine oil. There were some pneumatic valves installed but moist air resulted in corrosion in the supply lines and these types of valves were generally engineered out.

The dump condenser gas discharge outlet was originally connected to the A station gas stack. This arrangement allowed gas to back feed into the dump condenser causing severe corrosion of the steel and concrete. A separate outlet and remedial cladding solved this issue. The inlet steam pipework to the control valve was a dead leg that corroded through before appropriate drains and repositioning of the valve were undertaken.

In recent years, the majority of the station safety valves, with their maintenance and testing requirements, have been replaced by bursting discs. A new and larger capacity vent house has been built closer to the station, at Anchor 2, to improve pressure control during steam manoeuvring and machine trips.

5. TURBINES

This section discusses various aspects of the turbine plant.

5.1 Blading

The turbine blades were soft stainless iron, with the General Electric internal fir tree tangential entry root design. The blades were joined in short packets by banding retained to the individual blades by peened tenons. The closing blades were pinned to the rotor with rivets through the mid lines with the adjoining blades. Blades were of impulse design with little reaction, even in the last stages. The steam leakage was controlled by the axial seal of the knife edged front of the banding. The longer blades (greater than 300mm long) have crimped lacing tube at mid height to dampen vibration.

There have been 5 major types of blading problems over the life of the machines. The IP machine blades failed by cracking out of the pullface corners of the fir tree roots or out of the closing blade rivets. High cycle fatigue caused failures of some of the shorter blades at the base of the aerofoil. There have been banding failures as the tenons have cracked or the peened over edge has been stressed past yield. There has been cracking emanating out of the lacing tube holes. The leading edges of the last stages' blades have been eroded by water droplets. On the last stage of the MP blades, as much as 40mm of metal was removed from the outer extremity of the blade.

The IP blading issue was not solved until new rotors were fitted in 1990 (G1) and 1991 (G4). Among the attempted solutions were changing the number of diaphragm vanes, changing blading to higher strength material, peening and radiusing the root faces, and fitting lacing tubes. None of these significantly altered blade life. High cycle fatigue was addressed by long packet banding welding into 180° arcs. Use of fixed interval pre-punched banding was phased out in favour of punching the holes exactly where the blade tenons were, seeking to minimise bending stresses on the blades. Tenon peening methods were changed to minimise potential work hardening. Understrap welding was adopted for the higher stressed banding, especially when repairs were performed. Of special note was the last stage blade tenon failures that occurred very early in the life of the MP machines. To solve this problem, the banding was removed, new tenons formed by shortening the blades, lighter cross section banding fitted and both sides of every blade welded to the banding. Heat treatment was then performed using the turbine rectification lathe to slowly rotate the blades through a bath of molten lead.

In earlier times blade repairs were performed with parent metal but Inconel is now exclusively used. PWHT is adopted in all cases where this can be practically undertaken. Nothing was able to be done with the leading edge erosion except ensuring that the diaphragm interstage drainage functioned correctly. Some blades were refurbished by welding in new leading edges but modern manufacturing processes make new blades more cost effective than repair. Stellite leading edges have been tried but the life extension could not justify the additional cost. Station staff developed quite some expertise at reblading and modifying work practices to address the blade problems as they arose. The record time for blading work from trip until return to service is 44 hours. The shortest blade life is now a minimum of 120,000 operational hours but many blade rows, especially on the MP rotors, are still original after 280,000 running hours.

5.2 Diaphragms

The diaphragms and steam nozzles are of conservative design and construction being stainless iron vanes cast into a low grade cast iron body. The half joints are flush, with a radial key at the joint and an axial tongue and groove seal. The vanes were cut from sheet, the front edge rounded and a taper was machined on the trailing edge followed by curve forming of the blade in a press. The flush joint has partial blades supported by pinned buttons. On all machines, the critical clearances controlling steam leakage past the blades was a single axial seal between the trailing face of the diaphragm outer port wall and the tapered front edge of the banding. With the low pressure differential across even the reaction blading, this was deemed sufficient. There has been wash damage, particularly on the outer port walls with prominent ditching occurring around the upsteam face of the vanes. There have also been fatigue cracks in the vanes and some foreign object damage, particularly from blade failures. Wiredrawing and blast damage where the sealing faces haven't mated correctly also occurred. In the 1980s, the diaphragms were refurbished with stainless steel rings bolted into machined notches in the trailing section downstream of the outer port wall of the vanes. Capping welds were laided around the rings, more to seal the gaps with a smooth surface than to add strength. Vane damage was weld repaired using Inconel. Mild steel block repairs were undertaken where a vane defect was close to the port wall. Half blade pins were welded in and hardfacing deposited on the upstream face of the supports to reduce or stop erosion. Metal spray was then used to coat the exposed faces that had wash damage. Ceramic two pot fillers are used to repair minor damage. Repairs at subsequent surveys have continued to use these methods. Since these practices have been instituted, the condition of the diaphragms have not deteriorated.

5.3 Turbine Governors

The governors on the A Station machines were supplied with 1% droop. Frequency excursions from the grid with a machine partly loaded resulted in unstable station manifold pressures. It was not unusual for the LP turbines to cycle between no load and overload in a short time interval if there was a grid issue. The initial solution was to fully load the machines with the manifold pressure to suit. Changing the governor springs to 5% droop subsequently brought more stability.

5.4 Mid Life Machine Assessment

In the mid 1970s, concern was expressed that the nominal 20 year design life (Haldane and Armstead (1962) p 633) of the station was nearly up. A series of what was then termed mid-life reviews were undertaken over the next ten years that looked at the condition, life expectancy and replacement options for all major plant. The MP rotors are a shrunk disc shaft construction. One MP rotor was fully dismantled and inspected in 1978 because of concern expressed about potential corrosion and cracking in the keyways. No significant metallurgical defects were identified (Thain and Stacey 1984 p11). A turbine, representative of each type, was inspected by the manufacturer's engineers in conjunction with station staff. The opinion of the reviews was that with some refurbishment and ongoing maintenance, there were no foreseeable limitations on the plant's life. A range of non destructive testing (NDT) initiatives were introduced in this period. Much of the station pipework, particularly the IP exhaust and LP inlet pipework were replaced because of the wash erosion corrosion. This included the inter machine Howden condensate separators in the A station. Many other components were refurbished and newer technology, such as metal spray, was incorporated into the repair methods.

5.5 IP Machine Refurbishment

The two IP machines (G1 and G4) were extensively refurbished in the late 1980s. A design efficiency gain of 2% with the new steam path was identified as part of the project but the instrumentation was not accurate enough to quantify this post refurbishment commissioning. The rotors and diaphragms were replaced and the centre pedestal foundations were rebuilt. Oil had penetrated the shattered concrete pedestal foundation as a result of the blade failure vibration history of the machines. The damaged foundations were removed back to sound, clean concrete with the new foundations being cast using significantly better quality materials than those originally used. The concrete was then coated with oil proof paint before the machine pedestal was reinstalled.

The new IP rotors had a significantly sturdier blade design with each blade being pinned to the rotor. Thicker banding with titanium understraps connecting blading packets was also used. Since commissioning, there has been erosion on the leading edge of the tenons from condensate trapped between the J strips. This was solved by welding the front edge of the tenon up with hard facing and performing post weld heat treatment on the blades (Figure 5). Metal spray was also used to reduce erosion on the trailing face of the last stage disc.

The diaphragms have scarf joints and stainless iron trailing rings into which J strips were caulked for reducing radial clearances. They have stainless iron plate port walls into which the vanes were welded. This ring was then cast into the steel diaphragm body. Since installation, no wash repairs have been necessary on the diaphragms although the J strips have been replaced several times.

In recent years, the extensive erosive condensate wash of the IP machine mild steel exhaust casings became an issue requiring analysis. Numerous weld repairs and then metal spray were applied but these were only palliative measures. The weld repairs also caused warpage of the critical faces and some delamination of the casing walls. Finite element analysis has been used to safely extend the life of the exhaust casings when the erosion exceeded the manufacturer's allowance.

Figure 5 - Rotor heat treatment post weld repairs to remedy tenon erosion.

5.6 MP Inner Casing Replacement

The original MP inner casings were made of cast iron. They were subject to significant steam cutting, wash and handling defects. These defects also contributed to diaphragm damage. As repair options were limited, replacement was the only viable option. Finite element analysis was undertaken in 1992 to check the adequacy of a change in material to more erosion resistant stainless iron (Figure 6). The replacement units were cast and machined by NZ Railway workshops at Hillside, Dunedin, after reverse engineering the originals. The replacement stainless iron casings are still in near new condition with no significant maintenance having been required after 15 years service.

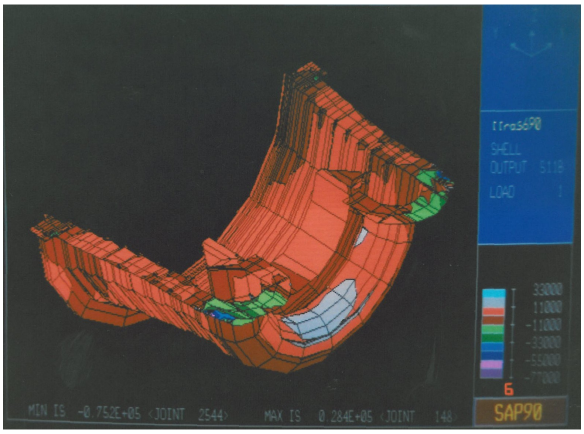

Figure 6 - Finite Element Analysis of the MP Inner casings 1992

6. BELLOWS

Bellows are used throughout the Wairakei station interconnecting steam pipelines and on some of the steamfield steam mains to allow for pipeline thermal expansion. The bellows material selected at the time of construction was 321 stainless steel. There were some pitting failures from chloride carryover in the steam but pipeline shutdown procedures along with production moving further away from station and the associated pipeline steam scrubbing by condensation has almost eliminated failures. Failures that occur now are usually high cycle fatigue failures from the bellows / expansion loops not being correctly set up. The bellows were originally fitted with internal shield sleeves. These had drainholes provided in bellows installed in vertical pipe runs. When these holes blocked, corrosion cells caused the welds to break. The disintegrated sleeves would then become foreign objects capable of partially blocking and damaging isolation and control valves. The shields were removed. Bellows made of Inconel 625 are now being used as replacements.

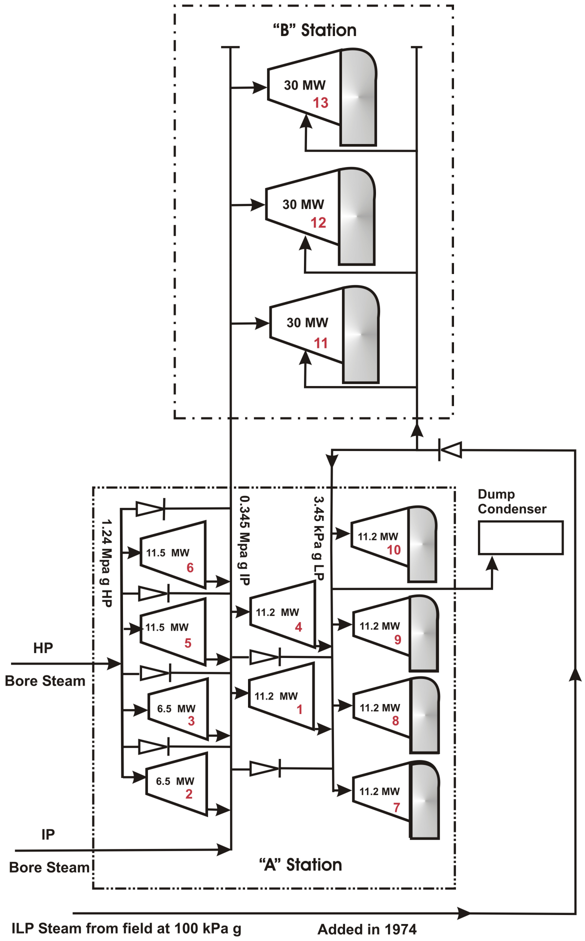

Figure 7 - Machine Configuration 1974 with the installation of the ILP steam main.

The commissioning of G14 in the ILP system in May 1996 saw the introduction of a new design of EPDM bellows. Figure 7 identifies the station configuration before G14 was installed to replace the ILP pressure reducing valves that had been in service since the ILP steam main had been installed in 1974. Figure 8 identifies the station configuration after commissioning of G14. The EPDM bellows were used on the LP steam lines as they allow additional movement. There have been a number of spectacular failures from water penetration through permeable sections of the inner surface causing internal corrosion of the steel stiffening wires and hydrolysis of the fabric. Time based bellows replacement is now a routine part of G14 machine surveys.

The machine steam strainers were removed in the mid 1980s as the steam lines were replaced. With steamfield production moving further away, debris was less of a problem. There was wastage on the strainer mesh and some cracking from high frequency vibration. Since removal, there have been no debris incidents that a strainer would have stopped.

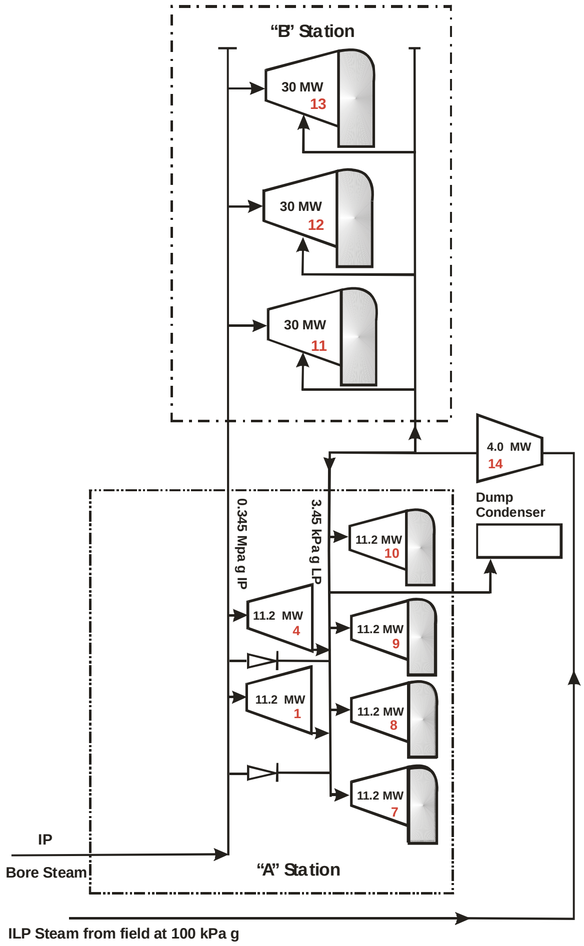

Figure 8 - Machine configuration at commissioning of G14 5 May 1996

7. COOLING WATER STRAINERS

The original cooling water cylindrical rotary strainer plates had 6mm diameter parallel sided holes drilled through 10mm thick Admiralty brass plate. The holes were prone to blocking by the pumice in the river water causing extended outages as the plugs of pumice had to be removed by hand. Initially seeking to over come the plugging issue all the holes were taper reamed from the inside of the drums. The plates subsequently suffered dezincification failing in service. To replace the plates, station staff and McEwen Industries developed a machine that could automatically index and drill the rows of tapered holes (22,000 per plate) from the inside of CuSilMan bronze plates (Thain and Stacey 1984 p14). These replacement plates lasted many years and generally were worn out by erosion from the debris trapped under the drum brushes and scrapers. The most recent rotary strainer plate replacements have used laser cut 3mm thick stainless steel.

8. ELECTRICAL

All of the generator endrings are ferritic. They have been removed at least once for inspection as well as NDT performed on the assembled rotors over the last twenty years (Figure 9). Arc damage was found in one rotor that necessitated replacement. For the remainder, machining defects and other damage were able to be dressed out after assessing the stresses using Finite Element Analysis. In situ balancing was performed after overspeed tests on return to service.

Figure 9 - Zip Scan of a generator rotor in 1988

There are three (originally four) banks of transformers at the station to step up the voltage from the 11 kV at the generators to the grid at 220 kV. Each transformer has at least two machines connected to it with unit circuit breakers. The transformers are single phase because of the construction size and weight limits. The transformers are regularly maintained with dissolved gas analysis and oil monitoring performed with filtration as needed.

The original exciters had thryatrons and pilot exciters. These were unreliable and it was part of the operators' routine to maintain the manual settings on the back up units. If the exciter in service tripped to backup the machine would remain on line rather than tripping. When spares became unobtainable in the 1970s the pilot / exciter equipment was replaced with electronic automatic voltage regulators (AVRs). The AVRs gave good service and are now being replaced by the next generation equipment, again because of parts obsolescence.

In the original design, the only motor driven valves were the unit steam isolators. All others, some of which were up to 48" diameter, were manual. That meant during a water in pipeline incident available operators had to run to the appropriate valves to shut them before the water reached the station. Many of these valves have since been motorised. All valves that are part of the failsafe systems are driven by hydraulics.

9. INSTRUMENTATION

When the station was built, there was no solid state equipment, not one transistor on the site. Circuitry used vacuum valves with all their attendant faults. The designers were not fully aware of the effects of H_2S on electrical equipment. Even the telephones could not be relied upon to work. There were many failures until pressurised clean air supplies and corrosion resistant contacts were fitted. The braze used to join components had to be changed to low silver composition. The wiring had to be changed to thermal stripped tin coated or pyro cables. As circuit boards and electronics were introduced and retrofitted, these were tropicalised. Gold plating was also used for electronic contacts.

The protection and control systems have been uprated as improved equipment has became available. PLCs formed a part of the upgrades. As the process control and fault logic improved, the station was able to be progressively demanned from 8 operators (minimum – with up to 12 on shift) to now one in the control room (controlling Wairakei, Wairakei Binary, Poihipi, Ohaaki and the Tauhara heat supply to Tenon) and as few as one roving operator who covers all the facilities. There is a double manned dayshift with two steamfield operators to do the ongoing routines, maintenance interface and plant monitoring. If an untoward event occurs, staff are available on callback. Under normal operation, very little operator intervention is needed as the plant runs itself. Even to run up and synchronise a machine to the grid usually only requires three staff, including the one in the control room.

Probably the best example of the improvements in instrumentation is the vibration protection. Initially, a weight suspended between two springs in an insulated tube operating through a mercury tilt relay provided a crude vibration switch. This was not reliable, primarily because of corrosion in the copper wiring joints. Invariably, machines had to be tripped by hand. It is part of station lore that operators usually knew when a blade had failed on the IP machines as the shaking caused the light bulb filaments in the control room to blow. Accelerometers on the pedestals were installed to give a loggable reading and to automatically trip the machines. The IP machines by this time had shattered their concrete foundations, so the protection worked reasonably well on these machines. The MP and LP machines were of a lot more solid design so it took significantly higher out of balance forces to get the vibration equipment to trip. Bently Nevada proximity probes on the bearing journals were next installed, with the actual vibration data going to the control room. The trip levels were set at 80% of the nominal bearing clearance. The most recent upgrade has the proximity probe data transmitted back through a fibre optic link to the control room. There, the operators set the alarm levels at just above the running levels.

When the original machines were installed, all the machine data was read directly from instruments on the machine or the gauge board beside the machine on the turbine floor. The only information sent to the control room was the generation data for display on the dial gauges. Originally the Operators undertook a half-hourly walk around log of data readings and this practice continued up until the late 1980s. To coincide with the commissioning of Ohaaki in 1988, the Wairakei Area Control centre was established as a remote supervisory facility for the Ohaaki and Wairakei Geothermal Power Stations. Computer (PDP11) based data acquisition facilitated data to be logged at half hourly intervals being available for analysis in daily tabular form. Currently after several further upgrades the data from over 11,000 points can be logged at programmable intervals with events timed to millisecond accuracy. The readings are available for trending, analysis and export.

10. MACHINE OVERHAULS

Originally, machine surveys were programmed on a two yearly cycle for the A Station machines and a three yearly cycle for the MP machines. Restrictions on staff working hours and the manufacturer's comprehensive work programme meant that these outages would take about six weeks to complete. Spare parts unavailability could extend these outage times.

In the mid 1980s emphasis was put on increasing the plant availability by shortening the length of the surveys. Changes in the work practices were implemented from using all in-house personnel to using contractors on shift work round the clock. Analysis seeking to reduce time spent on tasks by changing work methods was undertaken.

An example of this is the constructing of a frame to facilitate the rolling of the top MP casings by two cranes (Figure 10) rather than having to axially split the casing by unbolting and then rolling the two unbolted sections.

Figure 10 - Photograph of Top MP casing rolling frame in use in 2008

Processes were changed, for instance gritblasting components was changed to water blasting. As water blasting pressures have increased, now ultra high pressure water blasting equipment is used. With the low water volumes used, blasting can now be performed up on the operating floor. Additional tasks, especially those associated with NDT, were added to the work undertaken. The work packages were documented, planned and scheduled using critical path analysis to set the work programme focus. These measures reduced the machine survey outage times down to less than one month, typically 18-25 days, though every second survey where more inspection is performed takes an extra 10 days. Working with the third party inspection agency has enabled the lengthening of time between surveys. Documentation to support this included maintenance records and condition monitoring data from the machine surveys and in-service tests. This enabled the machine surveys to be scheduled on a five year cycle. This is currently being brought back to four years because of other work requirements.

11. NON DESTRUCTIVE TESTING

NDT has been performed over the life of the station during machine surveys. Initially, it was simple dye penetrant and magnetic particle inspection. Pulse echo and Time of Flight ultrasonic work, especially for parts like endrings or rotors was introduced in the 1980's. This has been supplemented in more recent times by phased array work on some of the potentially complex problem areas.

12. MACHINE UPRATING

Work performed in conjunction with the original equipment manufacturers and NZ inspection agencies allowed the official rating of the turbines to be lifted to that of the generators. This resulted in a nominally 10% increase rating for some of the machines. This rerating was achieved in 1998 once the original equipment manufacturer had reviewed the ratings and the original design data. Before this time some of the machines, particularly the MP turbine generators, had regularly been run in "overload" over the winter months so there was operational data to back up the design work.

13. PERFORMANCE.

Regular plant performance and work programme reviews are undertaken. Operational performance, especially generation, and identified defects are reviewed daily. There are combined steam supply and generation plant reviews undertaken weekly, seeking to ensure optimal utilisation of available steam and maximum generation. Intensive planning precedes machine or station surveys to ensure co-ordination with steamfield work and outside agencies.

Of the original 13 turbines, nine are still running at Wairakei and these machines have now clocked up over 3 million cumulative running hours. Availability is targeted at 95% with a forced outage factor of less than 1%. The last 20 years availability and forced outage data for the 9 original machines is plotted in Figure 11.

Peak power production, energy generation and load factor data since commissioning in 1958 is plotted in Figure 12 and Figure 13.

14. CONCLUSION

A range of considered engineered modifications, improved analytical techniques, use of superior materials, improved instrumentation, the shortening of survey outage times and focussed planning processes have all contributed to the improved availability, reliability and performance achieved by the Wairakei Steam turbine generators.

It is appropriate to acknowledge the dedicated efforts of the operations, maintenance, engineering and plant management personnel who have contributed to the remarkable performance achieved from the Wairakei Geothermal Power Plant since commissioning in 1958. A significant indicator of the work environment and dedication is the very low staff turnover. Even now, a significant number of the staff on the site has over twenty years service.

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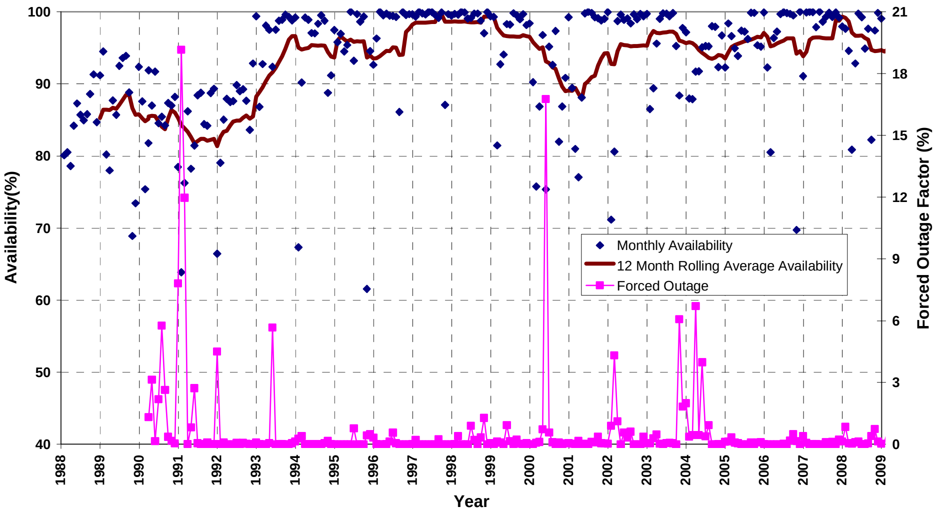

Figure 11 - Availability and forced outage factor data (1988 – 2009) for Wairakei Steam Turbine machines G1, G4, G7 to G13.

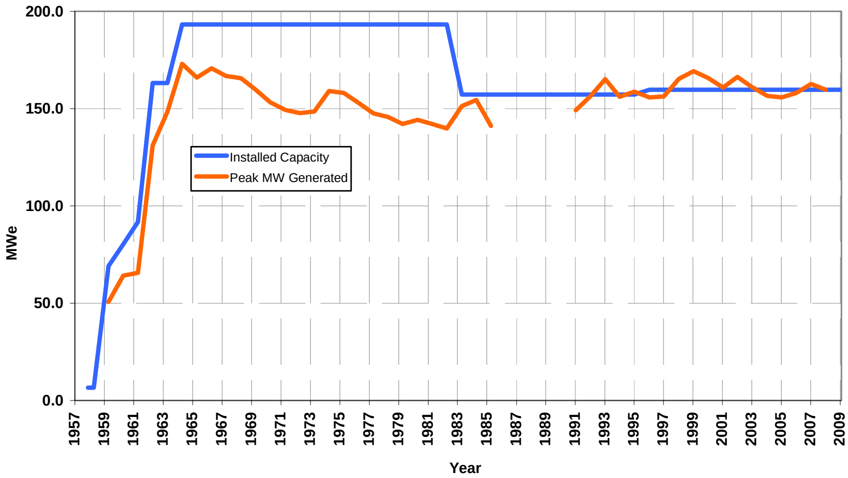

Figure 12 - Installed capacity and annual peak power generation data for machines G1 to G14 from 1958 t

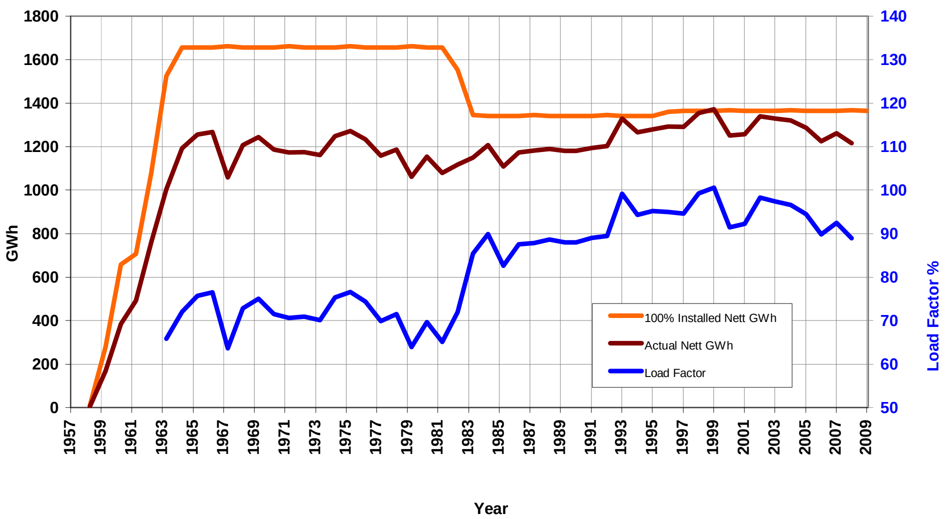

Figure 13 - Generation and load factor data for machines G1 to G14 from 1958 to 2008. Note the high load factors achieved since 1993. 100% load factor achieved in 1993 and 1999.