Replace and Renew, two projects to keep Ravensdown connected and the turbine running

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Abstract

This paper discusses the replacement of the 11kV Switchgear and the renewal of the steam turbine governor at the Ravensdown Ltd Christchurch plant.

Ravensdown manufacture and supply fertiliser to the New Zealand agricultural industry. The process of manufacturing super phosphate uses sulphuric acid which Ravensdown makes at its three production plants in Napier, Christchurch and Dunedin. Sulphuric acid is made through a catalytic conversion of sulphur dioxide gas generated by burning sulphur. The sulphur is burnt in a boiler; the waste heat is captured and used to drive a steam turbine generating electricity for the site and at times exporting to the local distribution network.

Commissioned in 1966 the Christchurch 11kV switchgear had exceeded its expected service life, and no longer met accepted safety levels for personnel operating and maintaining the equipment. The steam turbine was commissioned at the same time as the switchgear and whilst the original mechanical speed governor and inlet pressure regulator were still functional, both elements were becoming increasingly unreliable.

For these critical systems spare parts are generally difficult or even impossible to source; they have been kept operational for this long through the knowledge and skills of the Ravensdown operator/maintainers and a limited number of contractors. This specific knowledge and the skill set required to carry out repairs is disappearing from the labour force, gradually increasing the risk of repeated and extended forced outages that Ravensdown was exposed too.

This paper discusses the switchgear and turbine governor replacement projects completed by Ravensdown. The challenges and benefits of equipment selection, control and protection functionality and installation in a busy operating site is discussed.

Introduction

The sulphuric acid production process used at Ravensdown is the Contact process; a simplified schematic of the process is shown in Figure 1.

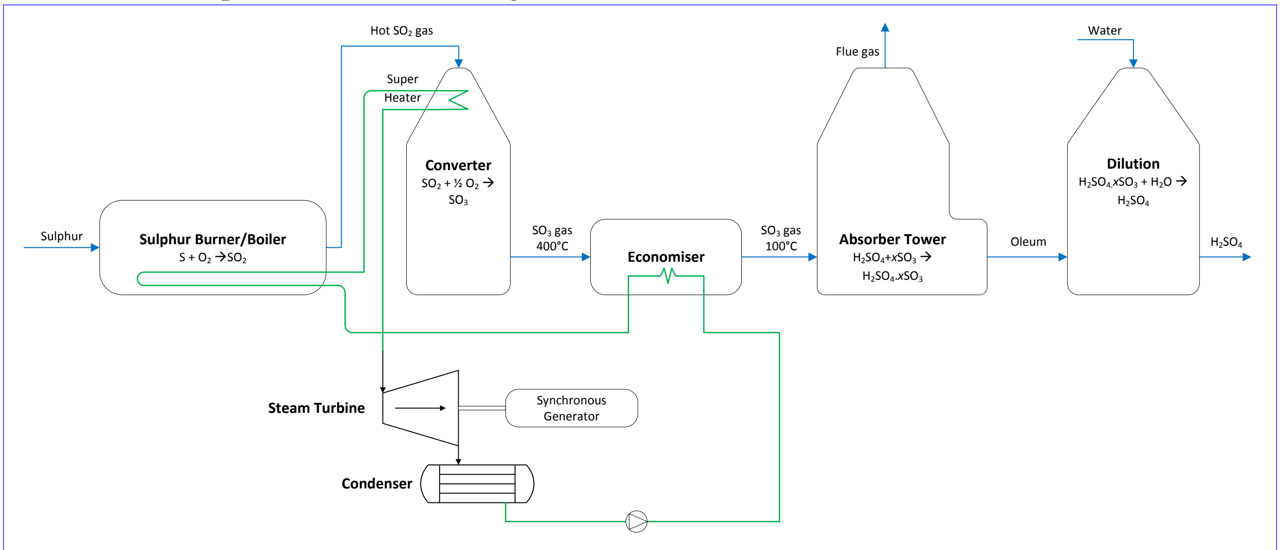

Figure 1 Contact Process for Sulphuric Acid Production

The burning of pure sulphur and the catalytic conversion process are exothermic, the heat of the reaction in the converter is maintained at 450°C and the excess heat used to produce superheated steam at 28.6Bar and 390°C to drive the steam turbine alternator. At the Christchurch plant the turbine has a rated maximum output of 3225kW with a speed of 6000rpm, driving a 4000kVA synchronous generator via reduction gear box.

The Christchurch site covers approximately 10 Hectres in Hornby as shown in Figure 2.

Figure 2 Ravensdown Site at Hornby, Christchurch and transformer locations

With site covering a significant area the various load centers are supplied from a private 11kV distribution network. The site single line diagram is shown in Figure 3.

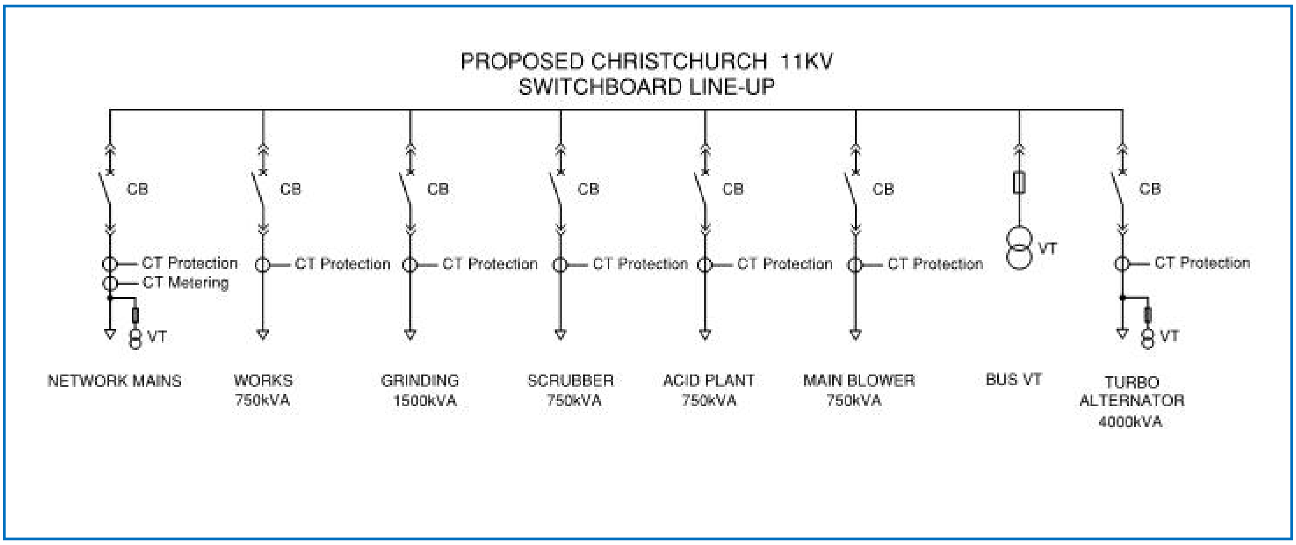

Figure 3 Ravensdown Christchurch Single Line Diagram

The site load consists predominantly of motors driving material handling equipment and the grinding mills that crush the raw materials required to manufacture the various fertiliser products. The HV switchboard is located in the Acid Plant, Figure 3 is the proposed line up and includes a feeder for the scrubber transformer. The scrubber system was installed in 2000 and the transformer was powered via a ring main unit that was connected in parallel with the grinding feeder.

The switchgear was the original equipment commissioned in 1966, it consisted of oil circuit breakers with electromechanical protection relays. All the circuit breakers with the exception of the generator CB were operated manually at the circuit breaker. In recent years there had been some minor upgrades that involved the switchgear such as the addition of power monitors and a new generator protection relay. Replacement of the switchgear was not an activity that was on the long-term plan, but a fault in the incomer cable termination in 2015 highlighted a number of issues with the switchboard and its location that ultimately could only be resolved by a complete replacement project. Due to the age of the switchgear repairs could not be carried out with sufficient confidence of there efficacy and so a temporary switchboard using a ring main unit was installed in an outdoor kiosk and the original switchboard was decommissioned. The temporary switchboard did not provide a connection for the turbine alternator. With no on site generation to compensate for the power drawn from the network, the cost to Ravensdown of not having a fully functional HV switchboard escalated quickly.

Switchboard Equipment Selection

The replacement switchboard was to be installed into the same space as the old switchboard. As part of the safety upgrades a dedicated HV switchroom was annexed off from the overall operations room that the switchboard was installed in. A new fire rated partition wall was installed and access to the switchroom was controlled.

The basic replacement specification was a like-for-like replacement, using modern industry standard equipment; the preferred technology was air/vacuum insulation. The switchboard would also have one more circuit breaker than the original to directly feed the scrubber transformer. The reuse of the existing switchroom imposed some dimensional constraints on the new switchgear so that cable trench could be reused without modification, which also influenced the positioning of the switchgear to provide the correct clearances all round. The original oil circuit breakers were withdrawable; initially this too was requirement of the replacement switchgear, but the eventual supplier provided an option using fixed circuit breakers at a lesser cost and with a narrower panel width. The fixed switchgear option was initially rejected as an element of old school thinking prevailed that considered the isolation provided by withdrawable switchgear was a necessity. Fixed switchgear is commonly used in distribution substations but it was argued that in a distribution situation there is redundancy in the system so a circuit breaker failure can be resolved quickly. In an industrial situation there is no redundancy in the distribution, however continuity of supply is not as important to a manufacturing environment where there are many other factors that can disrupt production that are more likely to occur than a power outage. What clinched the decision to use fixed circuit breakers was the realization that the main reason for withdrawable circuit breakers in the original switchgear was so that the oil could be maintained in the circuit breaker.

The protection relays used were SEL700 series. These were selected as they are widely used in the transmission and distribution industry, consequently, there is a large base of engineering and technical support, both locally and nationally. The SEL700 relays are very flexible in their configuration and arc flash functionality was included in each feeder relay. A motor protection version was used on the main forced draft fan, which is a 500kW LV induction motor that is direct on line started by the 11kV circuit breaker on the 750kVA main blower transformer. The relays were also able to provide feeder status indications and metering functionality over Ethernet to the Acid Plant SCADA system.

Demolition and installation

The demolition of the old switchboard proceeded quickly as it had been decommissioned some months previously. With the switchboard removed the room could be refurbished with the construction of a fire rated partition wall, new lights, and painting of the floor and walls. See Figure 4.

Figure 4 Demolition of the Old Switchboard, before and after

When the switch board was decommissioned all the cables were cut and left in place. The cable trench had approximately 50years of accumulated dirt, water and oil coating everything, as shown in Figure 5.

Figure 5 Cable trench before cleanout

New cables were installed for the turbine alternator, acid plant transformer and main blower transformer. New single core tails were installed of the works, grinding and scrubber feeders and inline joints made outside to the existing cables. When the temporary RMU switchgear was installed a new main incomer cable was installed and enough length left buried to re-terminate the cable in the switchroom. All the cables were installed in the trench using new cable clamps.

Figure 6 New HV cables and cable clamps

The switchroom floor was not the correct level tolerance for the new switchgear to be installed directly on the floor. A steal base frame was fabricated and fixed to the floor, with the switchboard modules then mounted on the base frame. This proved to be very helpful to the installation procedure as it allowed the panels to be easily maneuvered into place and all the inter-panel connections aligned. The switchboard installation in progress and the completed commissioned switchboard is shown in Figure 7.


Figure 7 Switchboard installation and as commissioned

The final component of the switchboard replacement was new remote control panel. The panel, shown in Figure 8, allows the acid plant operators to operate all the HV circuit breakers without having to go into the switchroom. The control panel includes the turbine alternator protection relay, Automatic Voltage Regulator and synchronizing controls.

Figure 8 Switchboard and Turbine Alternator Remote Control Panel

Governor upgrade
In comparison to the switchboard the turbine governor was still in working condition despite having not been in service for a little over a year when the switchboard was replaced. Like the switchboard the governor was still the original equipment as commissioned in 1966. However, not long after re-commissioning the turbine-alternator the inlet pressure regulator failed, which forced the turbine out of service whilst repairs were made. Then a short time later the speed setting mechanism started repeatedly jamming and turbine could not be synchronized. These controllability issues were not new, in particular the issue with the pressure regulator had occurred before. But the issues occurring in succession did highlight to Ravensdown that the governor system was a risk. Ravensdown's own operators knew that due to the age of the governor manufacturer's spare parts were no longer available and the number of people with the knowledge and experience to maintain and repair the old governor was very limited. The Author had previously proposed a governor upgrade to Ravensdown several years ago; during a Ravensdown/Beca social event the turbine issues were discussed, and the upgrade project was revived. It was not the intention of the upgrade to fully automate the turbine. The OEM operating manual details a number of manual checks and operations that must be done at various stages of the turbine start up would have been prohibitively expensive automate.

Turbine Control Description
The Turbine control consists of a mechanical fly weight governor that modulates the pressure of the control oil supplied to two pilot valve operated hydraulic servos on the turbine steam inlet. Like all fly weight mechanical governors, the operating speed is varied by the adjusting the force that counter-acting centrifugal force of the spinning fly weights. The speed adjustment range is limited to a band around the rated speed of the turbine. The mechanical governor is an Isochronous governor and could only be used for off-line speed control, or island mode operation of the site load, because it has no speed/load droop functionality. When an isochronous governor is operating in parallel with the grid it responds to the grid frequency perturbations, resulting uncontrolled power swings.

For the Christchurch turbine online operation is controlled by an Askania steam pressure regulator. The pressure regulator controls inlet steam pressure by varying the amount of steam admitted into the turbine. For the pressure regulator to take control of the hydraulic control oil to the servos, the governor speed setpoint has to be increased above the grid frequency. The mechanical governor, pilot actuated servo and the steam pressure regulator are shown Figure 9 Figure 10 and Figure 11.

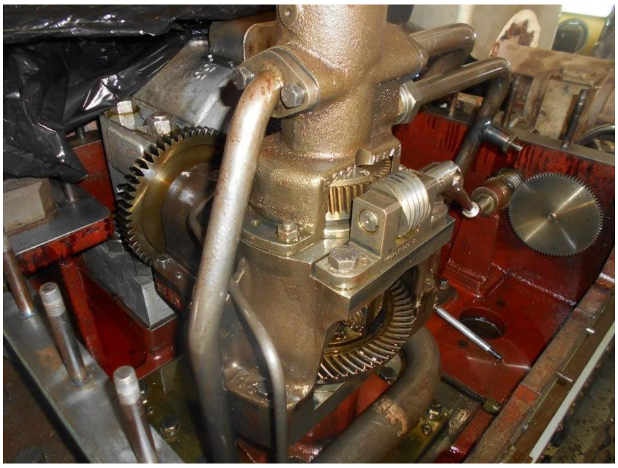
Figure 9 Mechanical Governor


Figure 11 Askania Steam Pressure Regulator


Figure 10 Pilot Actuated Hydraulic Servo

The hydraulic schematic of the mechanical governor system is shown in Figure 15.

With the governor system being entirely hydraulically actuated it has no mechanical linkages to wear out or become sticky; lost motion in linkages is a common cause of poor governor performance on other turbines. This feature of the Ravensdown turbine is explains how it has performed so well for so long. The inlet pressure regulator however has mechanical parts that are exposed to the steam header heat and pressure. The regulator balances the header pressure against the control oil pressure using sensing bellows on either side of knife edge balance point. The steam pressure sensing bellows had blown out several times and been repaired which reduced the sensitivity of the bellows. The linkages were wearing as was the knife edge balance point, and the regulator was not usable at low acid production rates where the turbine output was less than 500kW. At low production rates the waste heat was dumped in a cooling tower.

Governor Selection, Design and Installation

The governor upgrade project was conceived and agreed to on the basis that it could be completed on a budget that could be approved by the General Manager. Ravensdown had enough documentation to provide the justification for the upgrade; having been set the challenge Beca used the authors' experience with governors to bypass the conventional project methodology and directly select appropriate equipment and provide the detailed electrical design. Beca also recommended going directly to the HV switchgear installation contractor to provide a lump sum price for the installation of the governor upgrade since they were very familiar with turbine excitation and control panel in which the governor was to be installed. Finally, Beca recommended that the demolition of the mechanical governor system and the installation of the electro-hydraulic interface and the speed sensors was carried out by the Ravensdown acid plant staff. The Ravensdown acid plant engineer is a fitter and has many years' experience with the entire turbine system.

The selected governor was a Woodward 2301E-ST. The 2301E-ST is a steam turbine control with internal algorithms designed to start/stop, control, and protect a small steam turbine driving a generator, pump, or compressor. The pre-programmed application is configured by the user to suit the requirements of the site. The electro-hydraulic interface was a Woodward CPC-II. The CPC-II (current to pressure converter, generation II) is an electrohydraulic pressure-regulating valve control designed for use in positioning single-acting steam turbine valve servos. The CPC is field configurable to calibrate and adjust all internal functions and PID control settings. The installation of the electro-hydraulic interface is shown in Figure 12, and the revised hydraulic schematic is provided in Figure 16. Installation required plumbing into the pressure oil supply line, the control oil line to the servos and providing a drain line back to the tank.


Figure 12 Electro-Hydraulic Interface Installation

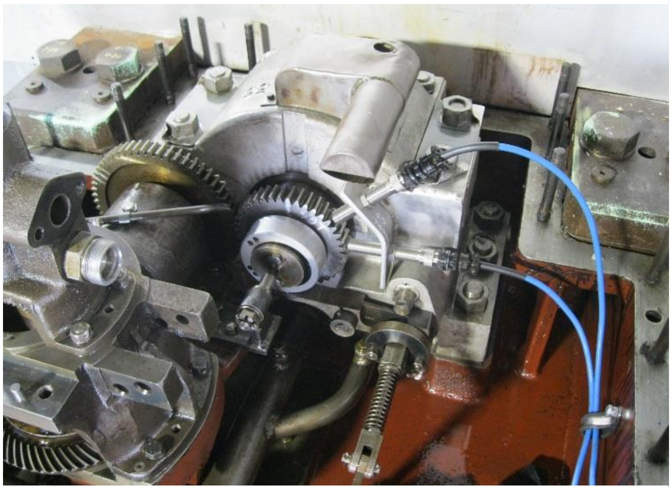
Figure 13 Speed Sensors Installation

Speed measurement was provided by two magnetic pick ups using an existing gear on the end of the turbine shaft. Two sensors are used for redundancy (Figure 13), and since this area of the turbine is normally inaccessible the number of teeth on the gear was checked more than once.

The 2301E-ST was configured to provide automatic turbine start-up. On start-up, the governor opens the steam valves according to the valve ramp schedule. The operator manually opens the main inlet/trip valve which admits steam to the turbine steam valves. The turbine accelerates until the speed control loop takes control of the turbine at the low speed reference of 500rpm to warm the turbine through and ensure that the shaft does not deform. The turbine is run at the low speed for approximately 15 minutes until the operator is satisfied that the turbine shaft is not deformed. Then the operator selects the rated speed setpoint from the local control panel and the governor accelerates the turbine to the rated speed at a controlled rate. The operator pauses the ramp to rated speed at 2000rpm via the local control panel to carry out final checks before continuing the ramp to the rated speed of 6000rpm. The governor was configured to avoid the critical speed band between 3000rpm and 5000rpm by ramping at twice the normal ramp rate through this speed band.

An auto-synchroniser was installed in the turbine control panel and the synch-check functionality of the SEL-700G protection relay was configured into service. For online operation the 2301E-ST was configured for process control of the steam header pressure. In process control a second PID controller is used to control an external process that is directly affected by the operation of the turbine. The process PID controller is cascaded with speed PID controller, steam header pressure feedback was provided directly to the 2301E-ST by new pressure transmitter on a 4-20mA loop. The pressure setpoint is set by the operator from the acid plant SCADA screen, as shown in Figure 14.

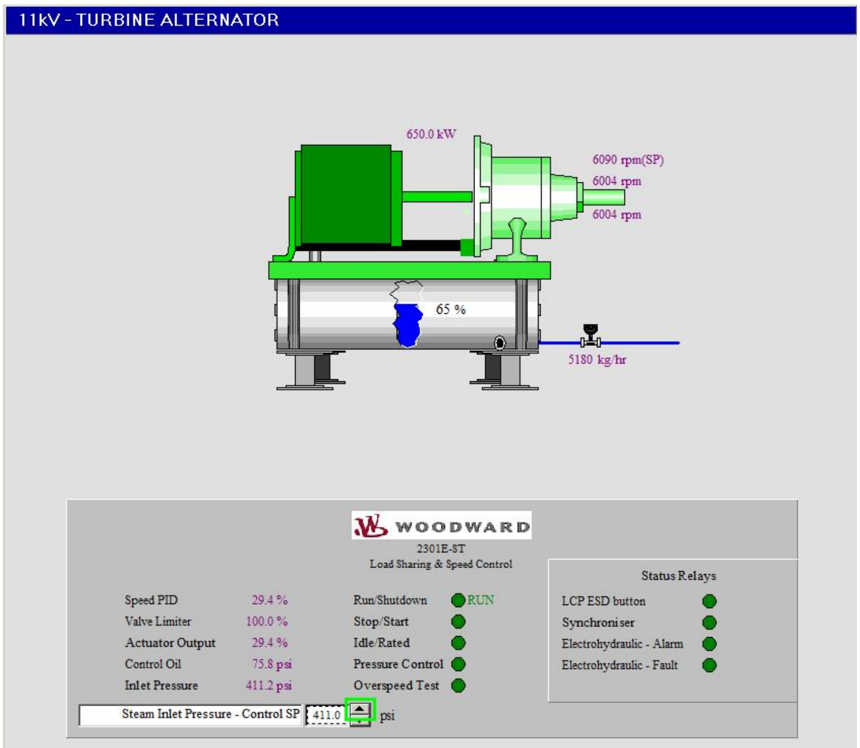

Figure 14 Turbine Governor SCADA Screen

The governor upgrade had an immediate effect on the operation of the acid plant, the turbine pressure control was stable at the minimum acid production rate with a power output of 350kW. This has allowed Ravensdown to run the turbine more minimizing there power demand from the network. The turbine-alternator is also used to correct the power factor of the site so that only real power is drawn from the network.

The start up operation of the turbine has been made much easier for the operators to manage. Previously the warm through process was manually controlled as the mechanical governor only operate at the rated speed. The first stage warm through speed of 500rpm was maintained by the operator continuously adjusting the main inlet/trip valve. The operator could not leave the turbine unattended during this stage as the speed would increase and risk damaging the turbine. With the electronic governor the operator can fully open the inlet/trip valve and the governor maintains the speed at 500rpm. The acceleration to rate speed with critical speed band avoidance and the pause at the second warm through speed of 2000rpm is consistent no matter which operator is rostered on. Consistency of the startup process can only beneficial to the turbine as the risk of damage through maloperation is significantly reduced.

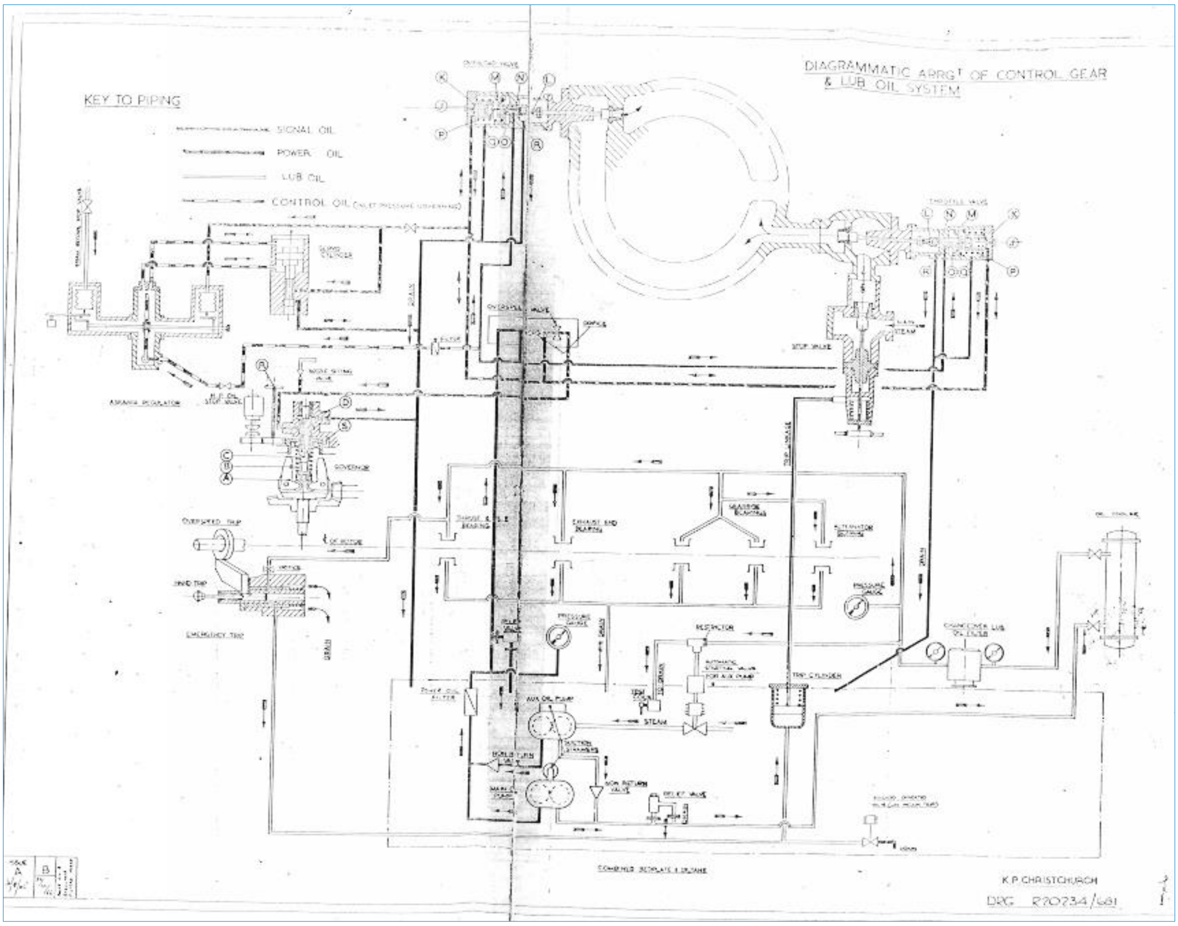

Figure 15 Hydraulic Schematic of the Mechanical Governor System

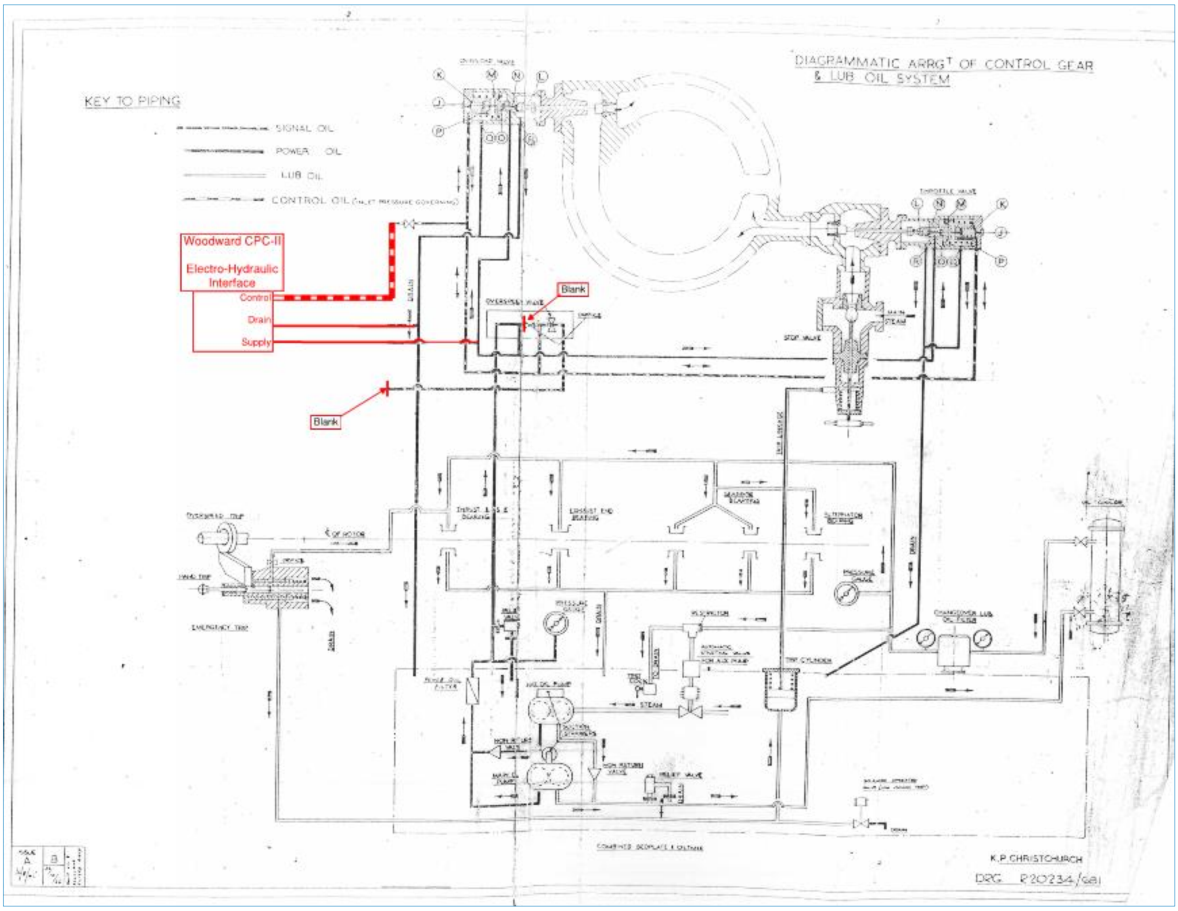

Figure 16 Hydraulic Schematic of the Electro-Hydraulic Interface