University of Southern Queensland

Faculty of Engineering & Surveying

50 kW Eddy Current brake

A dissertation submitted by

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in fulfilment of the requirements of

Courses ENG4111 and ENG4112 Research Project

Towards the degree of

Bachelor of Engineering (Electrical & Electronic)

Submitted: October, 2006

ABSTRACT

The project involves the refurbishment of the “Heenan-dynamometer” located underneath S block at the University of Southern Queensland.

The current system does not allow any computerized data acquisition. Upgrading the electronic control unit using solid state power electronic devices will enable users to perform better tests on engines and in the near future, it will allow the user to acquire digital data via a computer.

The actual dynamometer control unit uses valve technology to rectify the AC source and control the system output. The upgraded system will perform the same operation however is will use solid state devices. In order to use the new system on the dynamometer, a protective circuit based on pre-established conditions has been designed.

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Limitations of Use

CERTIFICATION

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Rudolph Edouard Bavarin

Student Number: 005 000 1428

Signature

Date

ACKNOWLEDGMENTS

This project would not have been possible without the involvement, assistance and moral support from several people.

I would like to thank my supervisor, Tony Ahfock for providing me with guidance and knowledge throughout the year.

I would also like to thanks the electrical and mechanical technicians for their help with respect to the practical side of this project.

Rudolph BAVARIN

University of Southern Queensland
November 2006

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CHAPTER 1 – INTRODUCTION

1.1 Justification for the project

A dynamometer is an instrument used to measure the driving torque of a rotating device coupled to it. The complete dynamometer system consists of a rotor made of a high-permeable magnetic material which is enclosed within a stator. To measure the torque generated by any rotating device coupled to the rotor, the stator is held in position by a force transducer which measures the force generated by the engine. In order to load the engine, the dynamometer needs a DC source to excite the stator coil and generate a steady magnetic field.

The actual dynamometer uses valve technology to convert AC to an adjustable DC source. The technology is obsolete and the dynamometer control circuit has to be upgraded. The valve rectifier will be replaced using solid state power electronic. To protect the dynamometer against overheating and the engine against over speeding, an upgraded protective circuit will be designed.The area of research for this project is limited to the design of solid state rectifier and an understanding of magnetic principle involved in the dynamometer mechanism.

1.2 Project aim and objectives

The University of Southern Queensland has a “Heenan-Dynamatic” Dynamometer, type G.V.A.L which uses valve technology to control the dynamometer. The actual control unit enables manual and automatic control of the load.

These two different modes of operation are obtained through a selector switch. When the switch is positioned on “governed engine”, the load is manually controlled. On a contrary, when the switch is positioned on “Ungoverned engine” engine, speed stabilisation is achieved.

This study focuses on the first mode of operation where manual control of the load is achieved using solid state device.

Specific project objectives were:

- Research and document the basic principles of the dynamometer.
- Familiarize with the existing dynamometer.
- Carry out tests on the existing dynamometer that will help with the design of the new DC supply.
- Design the new DC supply considering requirements such as open-loop/close-loop speed control option.
- Construct the DC power supply and test the upgraded system.

1.3 Dissertation outline

Chapter 2 gives a brief overview of how dynamometers are generally classified and briefly describes the "Heenan dynamometer". It also outlines the fundamental principle involved in the process used by the eddy current dynamometer.

Chapter 3 gives an overview of rectifier using solid state devices and demonstrates by means of experiments, the basic principles involved in half controlled rectification.

Chapter 4 describes the testing procedure used to locate the input and output connections of the valve rectifier. It also defines the main characteristic of the tacho generator which is located on the dynamometer shaft.

Chapter 5 explains the use of a protective circuit and briefly describes the protective system used with the valve rectifier. Following that, it gives a description of the selected devices used in the upgraded protection circuit.

Chapter 6 introduces the selected devices used for half controlled rectification and describes the operation of the upgraded system.

Chapter 7 describes the open loop configuration of the upgraded control unit and briefly explains how feed back control can be achieved.

CHAPTER 2 – BASIC PRINCIPLES

This chapter gives a brief overview of how dynamometers are generally classified and briefly describes the “Heenan dynamometer”. It also outlines the fundamental principle involved in the process used by the eddy current dynamometer.

2.1 Dynamometer

2.1.1 Dynamometer classification

Dynamometers are electro-mechanical instruments used to place a controlled mechanical load on rotational devices. Basically this type of machine is used to measure the generated power by the engine coupled to it. At the same time, dynamometers are also used for several testing procedures that help to define an engine’s characteristics and performance (Winther 1975). For example a dynamometer can be use to test engine endurance and determine its fatigue life under permanent stress conditions. From analysis of the results, preventive maintenance schedules can be organized to maintain good engine running conditions.

With most of the dynamometer, the torque-speed curves of the motor can be plotted, and their motor drives can be tested over an intended operating range.

When dynamometers are used to determine the torque and the power required to operate a coupled engine to it, they are generally classified as motoring or driving dynamometer. Similarly, when they are driven by a rotating device they are classified as an absorption dynamometer.

In addition to the previous classification, dynamometers can be classified as engine dynamometer where the engine is coupled directly onto the shaft of the dynamometer, or they can be classified as chassis dynamometers where the power is measured through the power train of the vehicle. Finally, dynamometers are classified by the type of absorption unit or absorber/driver that they use. Some units that are capable of absorption can only be combined with a motor to construct an absorber/driver or universal dynamometer (Winther 1975).

Types of absorption/driver units

- Water brake (absorption)
- Fan brake (absorption)
- Electric motor/generator (absorb or drive)
- Mechanical friction brake or Prony brake (absorption)
- Hydraulic brake (absorption)
- Eddy current or electromagnetic brake (absorption)

2.1.2 The Heenan-dynamometer

The dynamometer used for this project has been made by Heenan & Froude limited. The Heenan dynamometer type G.V.A.L represented in figure 2.1 uses the eddy current braking principle to apply a controlled load to the engine and measure the torque generated by the engine.

The machine consists of an absorption unit called the stator which is carried upon ball bearings so that it is free to swivel when braking occurs. The torque arm is connected to the stator and a weighting scale is positioned so that it measures the force exerted by the stator in attempting to rotate. The torque is the force indicated by the scales multiplied by the length of the torque arm measured from the center of the dynamometer. The rotor which is inside the stator is coupled to the tested engine and is free to rotate at any speed depending on the dynamometer operating mode.

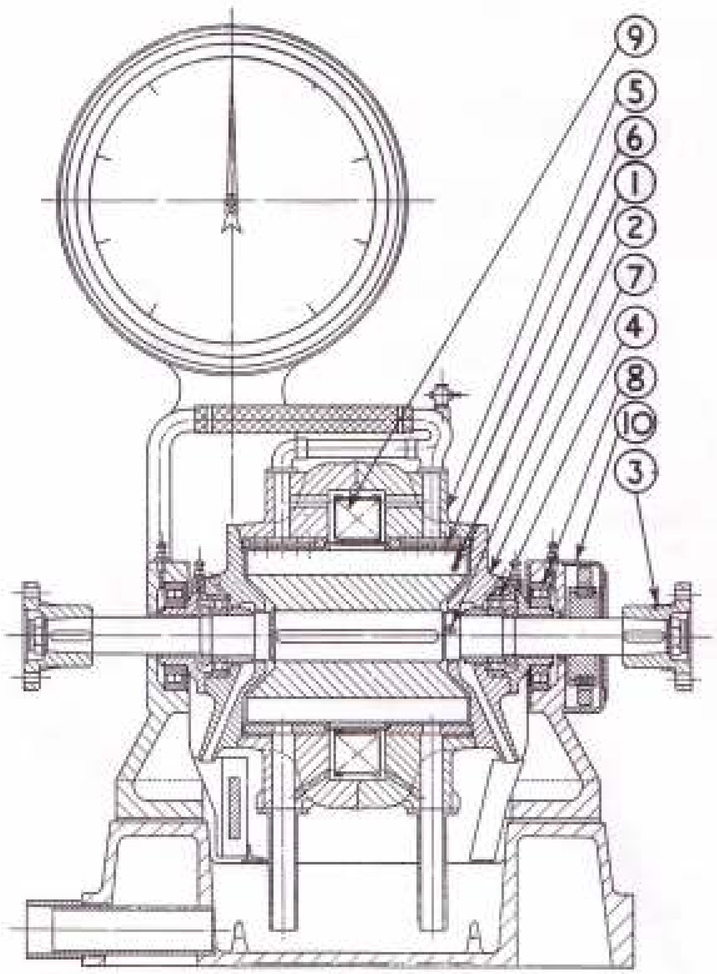

Figure 2.1: Dynamometer cross section

(Dynamometer handbook)

(1)	Rotor	(6)	Stator inner rings
(2)	Main shaft	(7)	Stator end cover
(3)	Half coupling	(8)	Stator trunnion bearing
(4)	Main shaft bearing	(9)	Field Coil
(5)	Stator	(10)	Governor Generator

For the braking process to occur, the dynamometer is securely bolted to substantial foundation. This assures steady running and eliminates most of the vibrations generated by the system (dynamometer handbook).

- Cooling system

The eddy current induced in the inner rings of the stator generates heat while the rotor is moving. The heat caused by the eddy current is cooled with water. Water is admitted to the gap between the rotor and stator and emerges through ports at the bottom of the machine (dynamometer handbook). To assure that temperature control is maintained while the system is running, a water pressure sensor switch has been included within the water cooling system. If failure of water supply occurs, the switch opens the protective circuit and thus shuts down the engine. In order for the inner rings to be cooled efficiently the quantity of water supplied to the dynamometer must be sufficient. Therefore, if the water pressure falls below an adjustable pre-set value the water pressure switch will open.

- Measuring the speed

The tachometer used in the system is classified as a tacho generator. There are two types of tacho generators, the AC generators which are used with the actual system and the DC generators. AC generators convert the shaft rotational speed into an analogue voltage signal.

One of the main characteristics of tacho generators is to output a voltage that is proportional in amplitude and frequency to the rotational speed. The generator is mounted onto the dynamometer shaft. The output of the generator is approximately 2 volts per 100 r.p.m (dynamometer handbook).

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- The control desk

This control unit has been built within a sheet steel control desk and is free to move at any distance from the dynamometer. This control unit is designed to operate from a single phase AC source. Located on the top of the control desk is the r.p.m indicating dial connected to the tachometer.

Figure 2.2: Control desk of the dynamometer

- Governed and Ungoverned option

The actual electronic control system is arranged to provide a D.C. voltage rectified from an A.C. mains supply. The control unit has been designed to produce two desired torque/speed dynamometer characteristic under specific running conditions. When the system is running under “governed” conditions, it provides a constant D.C. current which flows through the coil irrespective to any speed rise of the rotor. With this arrangement the dynamometer has a natural torque/speed characteristic as depicted in figure 2.3.

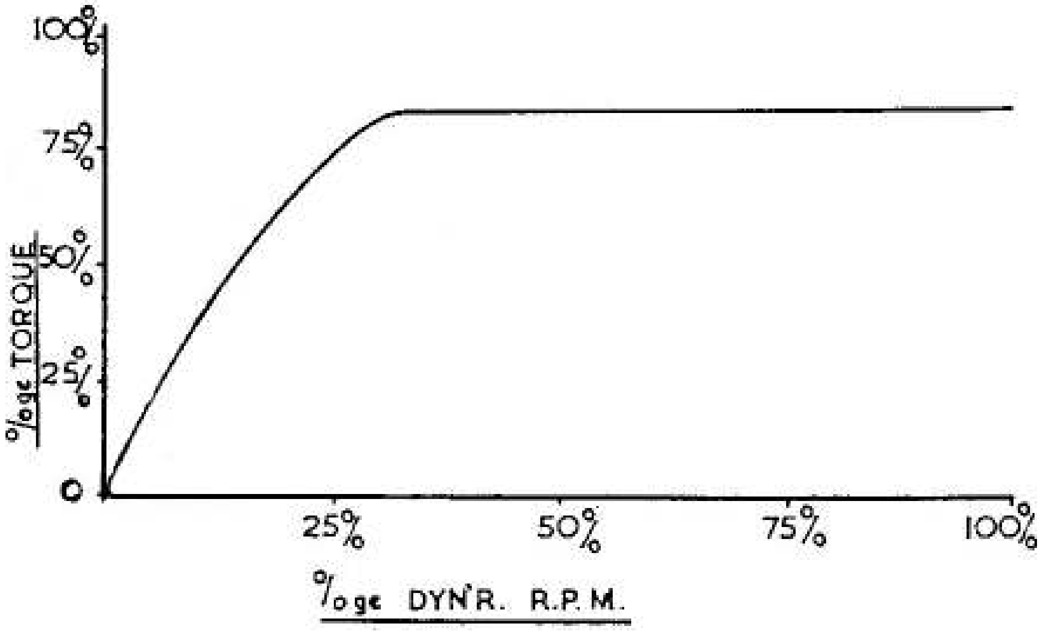


Figure 2.3: Torque vs. speed curve

(Dynamometer handbook)

When set for a given current, the torque rises steeply and then becomes constant irrespective of further speed increase. While the system runs under “ungoverned” conditions, the speed of the engine is stabilised. No current flows within the system until the speed has reached the controller preset value. Under this condition any increase of the engine speed is immediately counteracted by an increase of dynamometer load and if the engine speed drops, it will be counteracted by a corresponding drop in the dynamometer load.

2.2 Electromagnetic principle

Understanding the mechanism involved within the Heenan-dynamometer requires an understanding of the electromagnetic concepts applied to it. A permanent magnet has a natural magnetic field around it, as depicted in figure 2.4. The magnetic field, or field of influence, can be virtually represented by lines of magnetic flux. Those lines are completely closed curved, have a definite direction and are perfectly elastic (Sharma 2005).

Similarly, electromagnets generate a magnetic field with the same properties; however the latter relies on electric current to generate its field of influence.

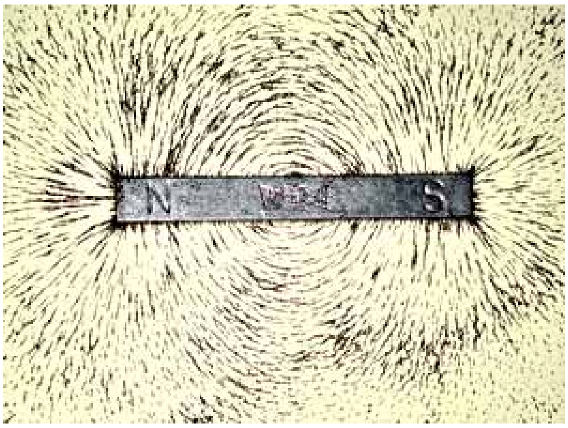


Figure 2.4: Magnetic field of a permanent magnet

(Source: http//www.geocities.com)

2.2.1 The magnetic field of a current carrying conductor

When direct current is applied to a piece of conductor it generates a steady magnetic field around it.

As represented in the figure 2.5, the surrounding field is generally represented by concentric circles lying on a plane perpendicular to the conductor.

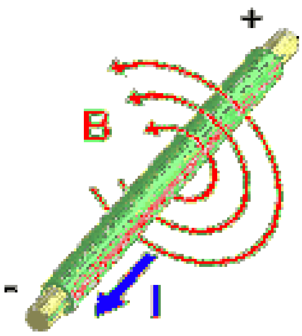


Figure 2.5: Magnetic field of a current carrying conductor

(Source: http//www. bibleocean.com)

When two direct currents flowing in the same direction are applied to two parallel conductors close to each other, the flux lines combine, and the two conductors attract each other.

However, when two direct currents flowing in the opposite direction are applied to two parallel conductors close to each other, the flux lines are crowded together in the space between the conductor, and the two conductors repel each other. Thus, when a direct current is applied to a solenoid, a magnetic field similar to the permanent magnet magnetic field is generated as illustrated in figure 2.6.

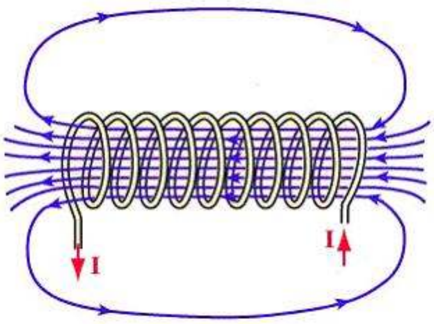


Figure 2.6: Magnetic field around a solenoid

(Source: http//www.schools.wikia.com)

The direction of flux line is defined by the right hand thumb rule. When the solenoid is held in the right hand so that the fingers points in the direction of the current flow, the thumb points to the north pole of the solenoid. Similarly, when a direct current runs trough the dynamometer coil, a magnetic field is generated. Figure 2.7 represents the steady magnetic field generated by the concentric coil within the stator of the dynamometer.

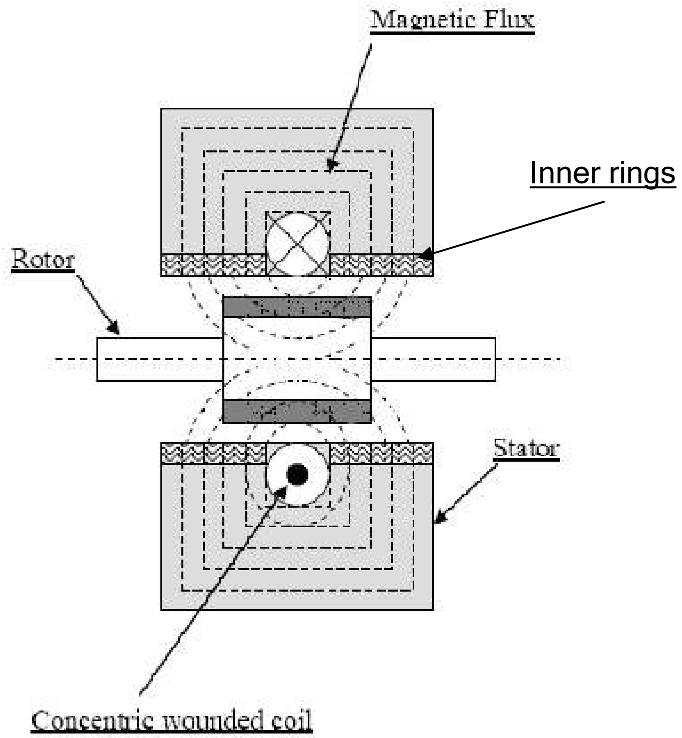


Figure 2.7: Magnetic field generated within the dynamometer

When current is flowing through the dynamometer's coil a magnetomotive force (*m.m.f*) also called a magnetic potential is created. The *m.m.f* produces the primary magnetic fields of the system and is given by equation (2.1). The *m.m.f* is proportional to the current and the number of turn of the solenoid.

$$m.m.f = I.N \text{ (Ampere-turns)} \quad (2.1)$$

N is the number of turns of the coil, I is the amount of current flowing through the coil.

In the dynamometer system the number of turns is fixed, consequently the magneto motive force will only be proportional to the amount of current through the solenoid.

2.2.2 Eddy current

When a moving magnetic field intersects a conductor, or a moving conductor intersects a magnetic field, current is induced. The relative motion causes a circulating flow of electrons within the conductor. These currents, also called eddy currents or Foucault currents, create electromagnets with magnetic fields that oppose the change in the primary magnetic field.

The *m.m.f* generated by these eddy currents is proportional to the strength of the original magnetic field, and also to the speed at which the magnetic field or the conductor is moving. These eddy currents are induced to the inner rings of the stator (see figure 2.7) when the rotor starts spinning within the magnetic field. The rotor is of high permeability steel and makes with the stator the magnetic circuit of the system. Because of this property, the flux lines are uniformly concentrated at the rotor pole tips to take full advantage of the available area. As a result, the density of the magnetic flux is not the same all around the rotor. Figure 2.8 illustrates the rotor pole tips and the concentration of the magnetic flux due to the magnetic property of the rotor.

The flux density is a vector quantity, and its magnitude is given by equation (2.2). In the SI system the unit of the magnetic flux density is Weber per meter square.

$$\overline{B} = \frac{\Phi}{A} \qquad (Wb/m^2) \qquad (2.2)$$

At the pole tips of the rotor the density of the magnetic flux is large because the fluxes are squashed into a small area. Everywhere else on the rotor the magnetic flux density will be weaker.

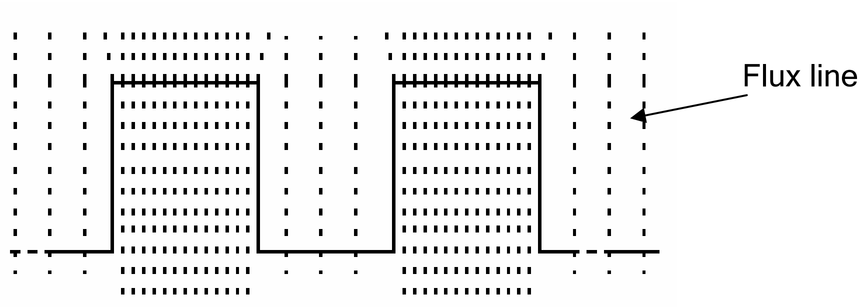


Figure 2.8: Magnetic flux density through the rotor

Because of the steady nature of the magnetic field, the rotor will not be affected by any change of magnetic flux density. Therefore no current will be induced on the rotor. However, while the rotor is moving, the inner rings of the stator are subject to a change in magnetic field density.

According to Faraday's law, whenever there is a relative motion between a conductor and a magnetic field, an electromotive force is induced in the conductor and is proportional to the rate of change at which the field is cut (Sharma 2005). In this case, the inner rings are held stationary and they are subject to varying magnetic fields produced by the rotation of the slotted rotor within the primary magnetic field. These electromotive forces are localized with the inner rings and generate eddy currents due to the resistive nature of the material. Fleming's Right hand rule can be used to define the direction of the induced electromotive force.

However, in accordance to Lenz's law, represented by equation (2.3), the eddy currents will always tend to oppose the change in field inducing it.

$$emf = -N\frac{\Delta\phi}{\Delta t} \tag{2.3}$$

Where N is the number of turn and $\frac{\Delta\phi}{\Delta t}$ is the change in flux with respect to time.

2.2.3 Electromagnetic braking effect

The magnetic fields created by the induced eddy current are called the secondary magnetic fields and they attempt to cancel the magnetic field causing it. This phenomenon generates new forces within the dynamometer. One force which acts upon the stator and another force which opposes the first acts upon the rotor, and thus decelerate its motion.

The force acting upon the stator forces it to rotate in the same direction as the rotation of the rotor. The absorption unit is securely bolted to a substantial foundation but is able to swivel clockwise or anti-clockwise depending on the force acting upon it. This tendency to follow the rotor rotation is counteracted by means of a lever arm connected to a sensitive torque measuring apparatus. When the stator swivels, the force applied to it is transferred to the measuring apparatus.

The stator is forced to follow the motion of the rotor but is not able to do so. As a result, opposing forces are created within the dynamometer. The force applied on the rotor is referred as braking force of the dynamometer and is controlled by the amount of current flowing trough the field coil.

CHAPTER 3 – RECTIFICATION

The actual dynamometer rectifier is obsolete and uses valve rectifier technology. To update the system with new power electronics, it is convenient for the University of Southern Queensland to change the valve rectifier with solid state devices. This chapter includes an overview of rectifier using solid state devices and demonstrates by means of experiment the basic principles for controlled rectification.

3.1 The power diode or rectifier diode

A diode is a two terminal device that allows an electric current to flow in one direction but essentially blocks it in the opposite direction. The diode circuit symbol is represented in figure 3.1. A semiconductor diode consists of a PN junction and the two terminals are called the anode and the cathode. Current flows from anode to cathode within the diode as shown by the arrow of the circuit symbol.

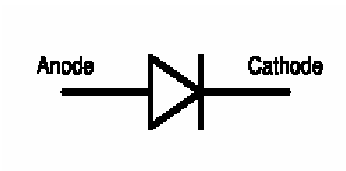


Figure 3.1: Diode circuit symbol

When the voltage across the diode is negative the diode is said to be reversed biased and behaves as an open switch assuming ideal diode characteristics. When the voltage is positive, the diode is forward biased and works as a close switch (Afhock 2005). Figure 3.2 illustrates the ideal operating characteristics of a practical power diode.

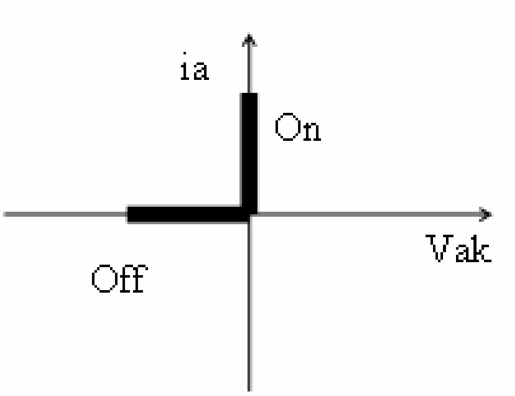


Figure 3.2: Idealised diode characteristic

3.2 The Thyristor or Silicon Controlled Rectifier (SCR)

A thyristor is a semiconductor device that has the same characteristics as the diode. Thyristors are often called silicon controlled rectifiers and compare to the diode the thyristor is a three terminal device. The main terminals of the thyristor are the anode and the cathode. The third terminal is referred as a gate. Figure 3.3 illustrate the thyristor circuit symbol.

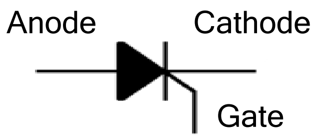


Figure 3.3: Thyristor circuit symbol

In the case that the thyristor is connected in series with a load through an AC source, no current flows through the circuit until the thyristor as received a triggering signal at the gate terminal.

When the pulse is received it triggers the thyristor and allows current to flow from anode to cathode. Figure 3.4 illustrate thyristor idealised characteristic.

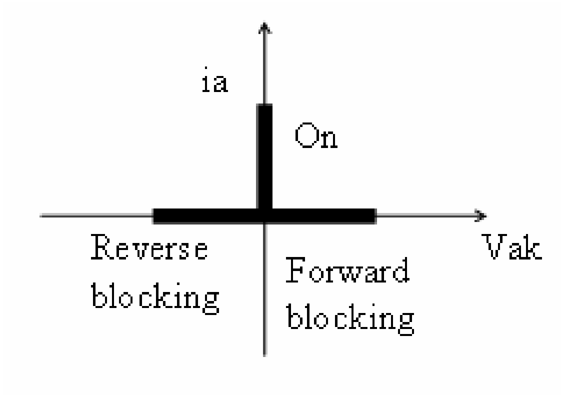


Figure 3.4: Typical thyristor characteristic

Once triggered the thyristor continues to allow current to flow through the circuit during the first half cycle of the supply. During the next half cycle the thyristor does not conduct because it is reversed-biased.

However, to conduct after been triggered, the current through the thyristor has to be higher than the latching current and last for a certain period of time. To turn off, the anode current is reduced below the holding current.

The most important characteristic of silicon controlled rectifiers is that conduction can be delayed in each half cycle, to achieve a variable output voltage. The triggering pulse causing the conduction of the thyristor to be delayed is generated by the firing module.

This delay of conduction is the delay between the instant the thyristor would have conducted if it was a diode and the time that it is triggered by the gate circuit (Ahfock 2005).

Figure 3.5 illustrates the delay of conduction also called the delay angle.

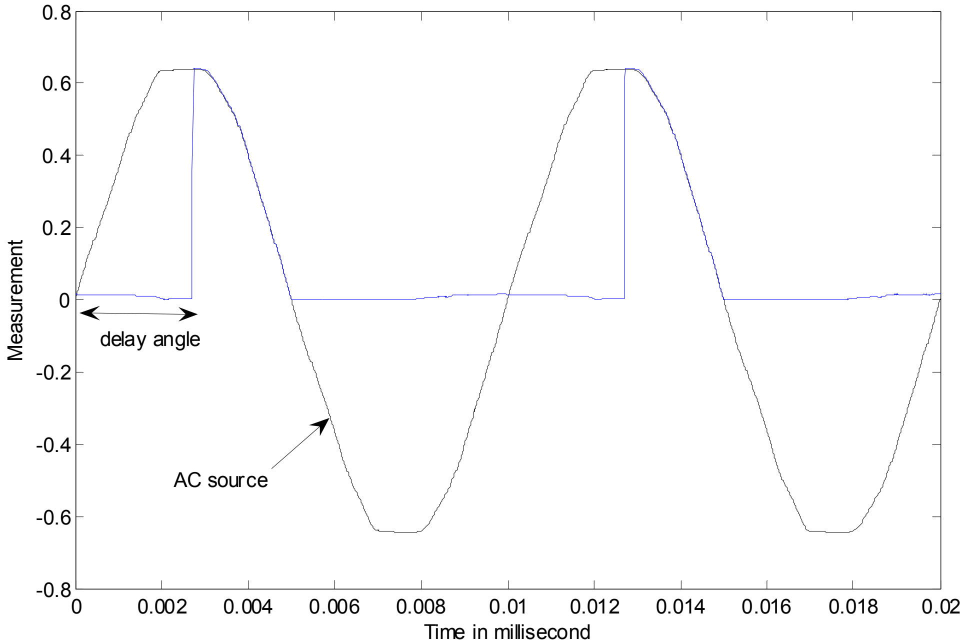


Figure 3.5: Half controlled half wave rectifier

- The firing module

The firing circuit must be designed so that it will only give a firing pulse during the time that the thyristor is forward biased. If the gate pulse is applied at the beginning of the half-cycle, the complete half-cycle will be applied to the load. If the gate pulse is applied anywhere else during the half-cycle, only a portion of the half-cycle is applied to the load. It is therefore possible to control the load voltage by controlling the gate pulse position.

This method of control is called linear firing angle control. To make sure that each triggering pulses occur at a precise phase angle, the line supply voltage is stepped down through a transformer and then sent to the triggering module. As the signal has been stepped down it is still in phase with the mains source voltage.

As a result, the gate terminal receives a pulse generated by the firing module that will trigger the solid state switch at a specific delay angle.

Figure 3.6 represents the block diagram of a triggering module and the waveforms obtain for the triggering process. Basically, a saw tooth generator outputs a saw tooth waveform (V_{st}) that resets at the zero crossings of the mains supply voltage. A controllable voltage (V_c) is generated by means of a potentiometer and compared to V_{st}. So the output of the voltage comparator (V_p) will be low if the control voltage is greater than V_{st} and vice versa. Finally, V_p is fed to a logic circuit and converted a triggering pulse which is sent to the thyristor gate terminal. (Afhock, 2005).

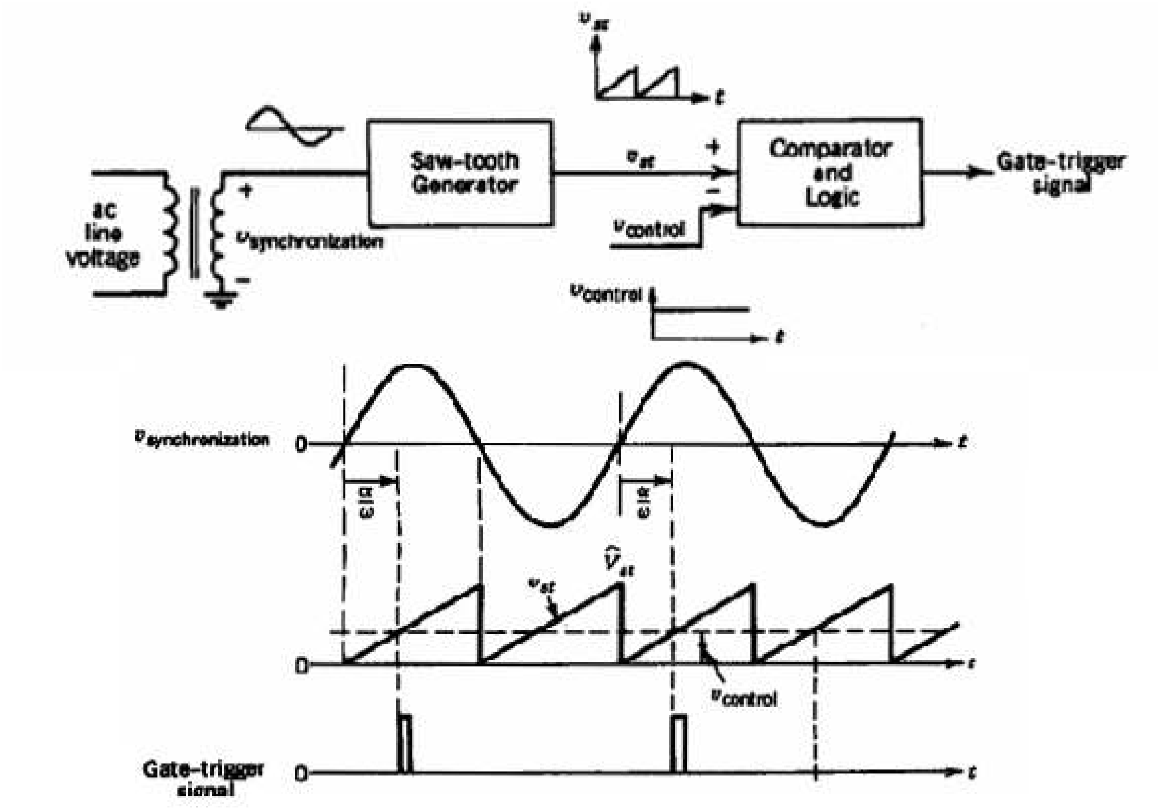


Figure 3.6: Gate trigger control circuit and waveforms

(Wiley 2003).

3.3 Rectifiers configurations

The coil of the dynamometer requires direct current to generate a steady magnetic field for the braking process to occur. Consequently, conversion of AC to DC must be achieved.

3.3.1 Half and full wave rectification

The process of converting AC to DC is called rectification. The majority of the DC loads respond to the mean value of a periodic wave form. To obtain the mean value of a periodic signal, the integral of the signal during one period is divided by the period in which it occurs. The waveform obtained from the mains is similar to a sinusoidal signal represented in figure 3.7. When using the mean value formula on a sinusoidal signal, the result will be zero as the net area for one period is equal to zero.

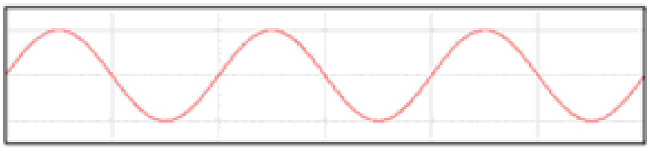


Figure 3.7: Sinusoidal wave form

Nevertheless, by means of solid state technology it is possible to change the form of the input signal and obtain an applicable mean value of the supplied voltage for the device to operate in DC mode. There are two main manipulations that can be achieved when rectifying a sinusoidal signal. The half wave rectification or the full wave rectification.

- Half wave rectification

The process of removing one half of the input signal to establish a DC level is called half wave rectification.

In half wave rectification the positive or negative half of the AC wave is passed easily while the other half is blocked, depending on the polarity of the rectifier. Figure 3.8 demonstrates half wave rectification of a sinusoidal signal.

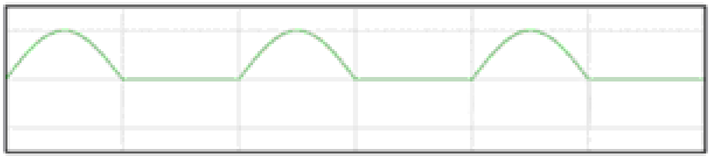


Figure 3.8: Half wave rectification

The simplest form of rectifier circuit is a diode connected in series with the ac input. During the positive half cycle of the input voltage the current represented in figure 3.9 flows through the load resistor. The diode offers a very low resistance and hence the voltage drop across it is very small. Thus the voltage appearing across the load is practically the same as the input voltage at every instant. During the negative half cycle of the input voltage the diode is reverse biased. Practically no current flows through the circuit and almost no voltage is developed across the resistor.

So, when the input voltage is going through its positive half cycle, the output voltage is almost the same as the input voltage and during the negative half cycle no voltage is available across the load. This explains the unidirectional pulsating DC waveform obtained for half rectification in figure 3.8.

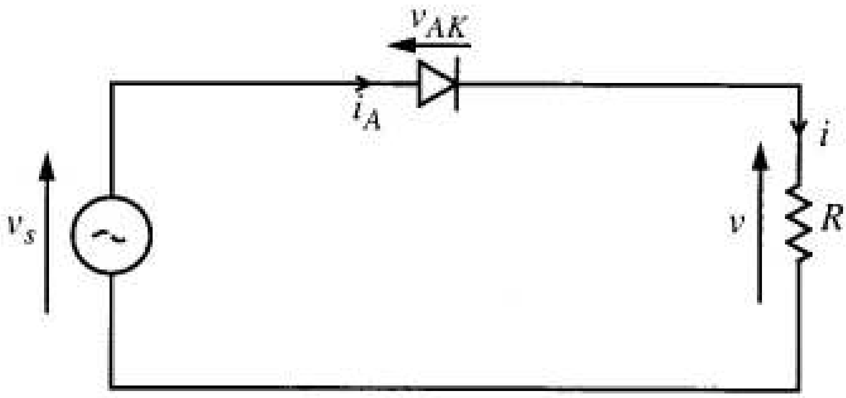


Figure 3.9: Rectifier circuit with one diode

(Ahfock 2005)

This rectifier configuration is classified as uncontrolled rectification. In half wave rectification the AC source only works to supply power to the load once every half-cycle, meaning that much of its capacity is unused. However, half-wave rectification is the simple way to reduce power to a resistive load.

<u>The Average voltage or the DC content of the voltage across the load is given by:</u>

$$V_{av} = \frac{1}{2\pi}\left[\int_{0}^{\pi} V_{peak}.\ \sin\omega\ t\ d(\varpi t) + \int_{\pi}^{2\pi} 0.\ d(\omega\ t)\right]$$

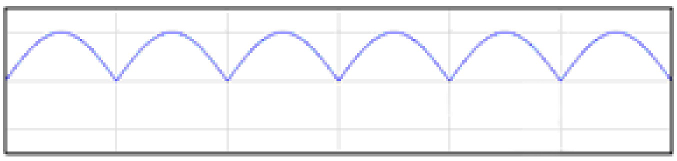
$$V_{av} = \frac{V_{peak}}{2\pi}\left[-\cos\omega\ t\right]_{0}^{\pi}$$

$$V_{av} = \frac{V_{peak}}{\pi}$$

$$I_{av} = \frac{V_{av}}{R} = \frac{V_{peak}}{\pi.R} = \frac{I_{peak}}{\pi}$$

- Full wave rectification

Figure 3.10 illustrates full wave rectification of the same sinusoidal signal. The negative or positive portions of the alternating signal are reversed and thus produce an entirely positive or negative signal waveform depending on how the diodes are connected.



<u>**Figure 3.10: Full wave rectification**</u>

For greater efficiency, it is more convenient to use both halves of the incoming AC source. A rectifier that converts both half-cycles of an AC voltage waveform to a series of voltage pulses of the same polarity is called a full wave rectifier. To obtain full rectification, a different rectifier circuit configuration must be used. Full wave rectifier uses a four diode bridge connection which is illustrated in figure 3.11. If the AC is centre-tapped, then the diodes are arranged anode-to-anode or cathode-to-cathode to form a full-wave rectifier.

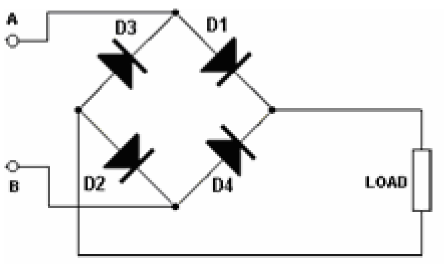


Figure 3.11: Diode Bridge rectifier

For the diode bridge circuit, the input signal is a sinusoidal voltage source. During the first half cycle, the voltage is positive. Consequently at point A the voltage is positive and at point B the voltage is negative.

The Anode of D1 and D2 is positive and the cathode of D1 and D4 is negative. During the first half cycle, A is positive and B is negative, consequently diode D1 and D2 are forward biased and current flows from the source through D1, the load and D2 and back into the source.

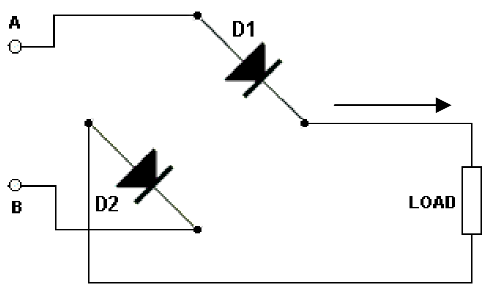


Figure 3.12: Flow of current during positive cycle

During the next half cycle, the voltage at point A is negative and the one at point B is positive. As a result D4 and D3 are forward biased because their anode voltage is positive and their cathode voltage is negative. During this period of time the current will flow around the circuit as shown in figure 3.13, again flowing in the same direction through the load and producing another positive pulse of voltage.

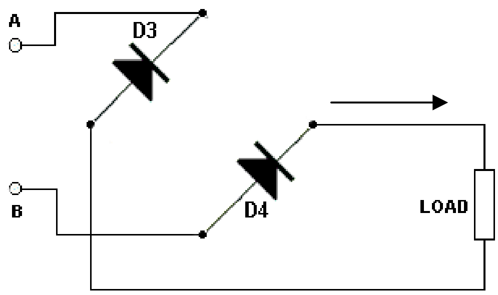


Figure 3.13: Flow of current during negative cycle

The process of full wave rectification is illustrated in figure 3.10. When bridge rectifiers use only diodes they are said to be uncontrolled. So as long as the AC input does not vary it is not possible to adjust their D.C output. However, combining diodes and thyristor within a bridge configuration leads to phase controlled rectification.

The Average voltage or the DC content of the voltage across the load is given by:

$$V_{av} = \frac{V_{peak}}{2\pi}\left[\int_{0}^{\pi} \sin\omega\, t\; d(\omega\, t) - \int_{\pi}^{2\pi} \sin\omega\, t\; d(\omega\, t)\right]$$

$$V_{av} = \frac{V_{peak}}{2\pi}\left[-\cos\omega\, t\right]_{0}^{\pi} - \left[-\cos\omega\, t\right]_{\pi}^{2\pi}$$

$$V_{av} = \frac{2.V_{peak}}{\pi}$$

3.3.2 Half and fully controlled rectifier

By using different combinations of diode and thyristor it is possible to obtain different classes of rectifiers. Mainly because of the thyristor characteristic of being able to be phased controlled, rectifier are said to be fully controlled when using four thyristors within a bridge configuration.

The fully controlled bridge is usually used when it is necessary to regenerate power form the load. The most widely used rectifier configuration is the half-controlled bridge illustrated in figure 3.14. The main advantage of using half controlled rectification is to provide the load an adjustable D.C output voltage that varies with respect to the delay angle.

For most of the applications using half controlled rectifiers, the control is only possible during positive output voltage from the mains, and no control is possible when the mains cycles are negative.

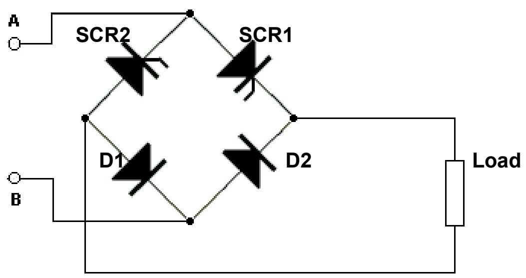


Figure 3.14: Half controlled bridge rectifier (SCR serie)

3.4 Testing on phase controlled rectifier

A series of tests on a half controlled rectifier provided by the engineering faculty have been conducted in order to understand the process of rectification using this configuration. In the following experiments two different rectifier configurations have been used.

Most of the power electronic applications operate at a relative high voltage and in such cases the voltage drop across the SCR tends to be irrelevant for such application. So, most of the time, the conduction voltage drop across the device is assumed to be zero for circuit analysis. Similarly, it is also valid to assume that the current through the thyristor is zero when it is not conducting.

3.4.1 The half controlled bridge rectifier

There are two single phase half controlled rectifier configurations and both operate in a same manner when connected to a resistive load. Figure 3.14 illustrate thyristors in series configuration and figure 3.15 shows the parallel thyristors' configuration.

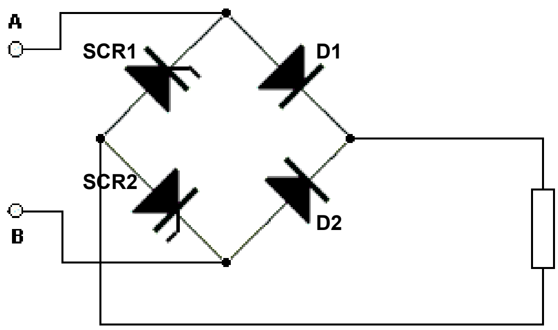


Figure 3.15: Half controlled bridge rectifier (SCR parallel)

The delay angle has been fixed to a particular value and the circuit is operating at steady state. During the first half cycle of the AC source, the voltage at point A is positive with respect to B. So, the load current flows only if SCR_2 is triggered. SCR_2 is then turned off when the source voltage becomes negative. During this cycle, B is positive with respect to A, so that SCR_1 and D_2 conduct the load current when SCR_1 is triggered. However, during the laps of time when SCR_1 has not been triggered, the load current keeps flowing if the load is highly inductive.

This inductive current has two circuits where it can flow, one made by the SCR_2, the source and D_1 and a second, made by SCR_1 and D_1. Because of the low impedance of the second circuit, the current continue to flow through SCR_1 and D_1 while the voltage is negative.

The back e.m.f from the inductive load drives current through the bridge without containing any of the reverse supply voltage. During this time interval the load current decays exponentially. Thyristor SCR_1 is then triggered in the next half cycle and the cycle repeats. Figure 3.16 illustrates the output of a half controlled bridge rectifier connected to an inductive load.

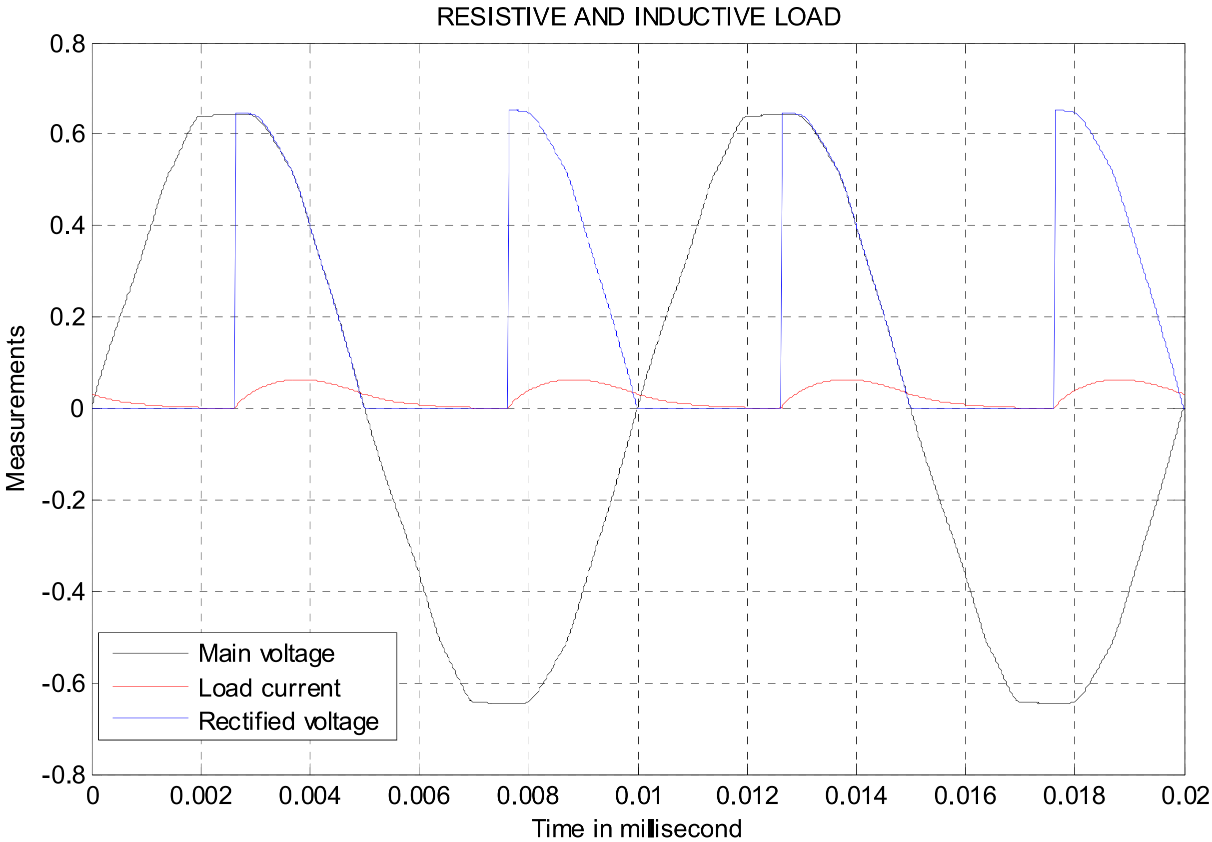


Figure 3.16: Half controlled bridge rectifier output

This half control rectifier configuration is good when the load is not too inductive and with a time constant much lower than one half cycle of the supply. On a contrary, if the load is highly inductive with a time constant greater than one half-cycle of the supply, it will become more difficult to turn off the load current just by not sending any pulse to the gate.

If the trigger pulses are removed after that a thyristor has been triggered, this thyristor will continue to conduct as usual for the rest of the half cycle of the supply. Then, the other thyristor will not turn on because no triggering pulse will be sent to assure conduction. The circuit will continue to operate indefinitely with the first triggered thyristor conducting on complete alternate half cycle and acting as a flywheel diode on the other half cycles. In this case, the only way to interrupt this cycle will be to stop the mains supply. Nevertheless, to ensure that the circuit operates satisfactorily a free wheeling diode can be added in parallel to the load. Consequently, at the end of each half cycle of the supply the load current is transferred directly to this diode. The free wheeling diode ensures that there is no risk that a thyristor will continue to conduct over another half cycle. (ed. Mullard 1970).

The average output voltage of the bridge as a function of firing angle:

$$V_{av} = \frac{V_{peak}}{\pi}\left[\int_{\alpha}^{\pi} \sin\omega\ t\ d(\omega\ t)\right]$$

$$V_{av} = \frac{-V_{peak}}{\pi}\left[\cos\omega\ t\right]_{\alpha}^{\pi}$$

$$V_{av} = \frac{-V_{peak}}{\pi}[\cos\pi - \cos\alpha]$$

$$V_{av} = \frac{V_{peak}}{\pi}[1 + \cos\alpha]$$

The RMS load current during α < wt < π :

$$i_{load}(\omega\ t) = \frac{V_{peak}}{Z} \times \sin(\omega\ t - \beta) + [A \times e^{-\frac{\varpi t - \alpha}{\tau}}]$$

$$where$$

$$Z = R \times \sqrt{1 + \tau^2}$$

$$\tau = \frac{\omega L}{R}$$

$$and\ -\beta = \tan^{-1}(\tau)$$

$$i_{load}(\pi) = \frac{V_{peak}}{Z} \times \sin(\pi - \beta) + [A \times e^{-\frac{\pi - \alpha}{\tau}}]$$

TheRMS load current during π < wt < π + α :

$$i_{load}(\omega\ t) = i_{load}(\pi) + [^{-\frac{\varpi t - \pi}{\tau}}]$$

When the load current is repetitive

$$i_{load}(\alpha) = i_{load}(\alpha + \pi)$$

$$i_{load}(\alpha) = \frac{V_{peak}}{Z} \times \sin(\alpha - \beta) + A$$

$$i_{load}(\pi + \alpha) = \frac{V_{peak}}{Z} \times \sin(\pi - \beta) \times e^{-\frac{\alpha}{\tau}} + A\ e^{-\frac{\pi}{\tau}}$$

$$A = \frac{V_{peak}}{Z} \times \frac{[\sin(\pi - \beta)] - \sin(\alpha - \beta)}{1 - e^{-\frac{\pi}{\tau}}}$$

Once A is known, the total RMS value of line current and the RMS value of its fundamental component can be estimated.

3.4.2 Fully controlled half wave rectifier with a free wheeling diode

The operation of this rectifier configuration is very similar to the single diode circuit represented in figure 3.9. The only difference is that this configuration uses a thyristor connected in series with the load and a diode connected in parallel.

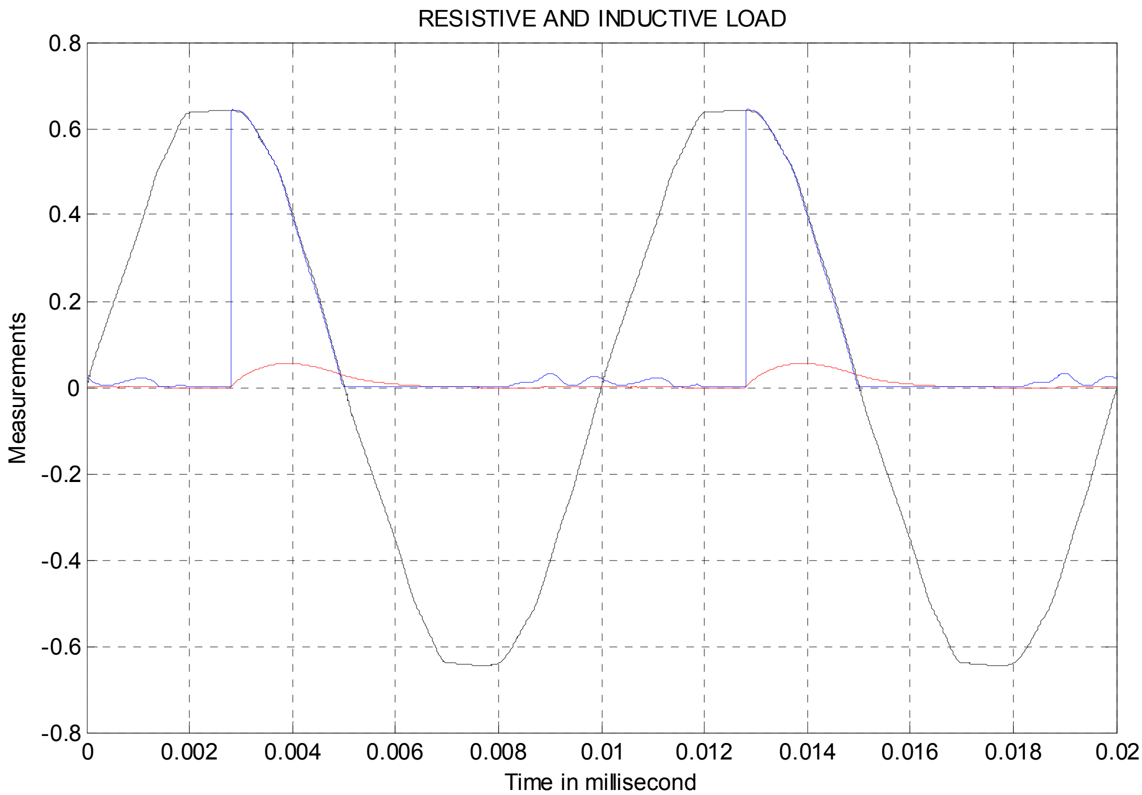


Figure 3.17: fully controlled half wave rectifier output

In the first positive half cycle, the thyristor is forward-biased however it will only conduct if the device will receive the firing pulse. If it is not triggered, no current will be delivered to the load.

As explained earlier, when the thyristor is triggered in the forward-bias state, it starts conducting and the positive source keeps the device in conduction until the source voltage becomes negative. At that instant, the current through the circuit is not zero because there is some energy that has been stored in the inductor.

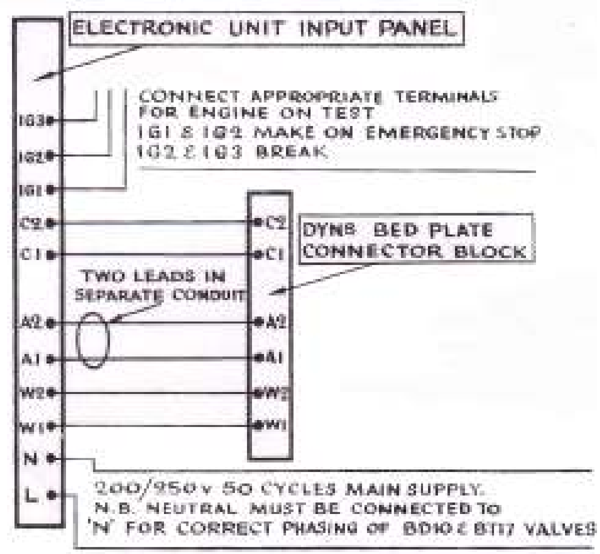
The inductor discharges this energy during the negative cycle of the mains source through the free wheeling diode. So, when the free wheeling diode conducts, the thyristor remains reverse-biased, because the source voltage is negative. In the absence of the free wheeling diode, the inductor would keep the thyristor in conduction during the negative cycle of the source voltage until the load is fully discharged.

CHAPTER 4 – TEST AND DESIGN

The updated half wave rectifier has to be tested on the dynamometer. Subsequently, tests will be implemented in order to localise where the upgraded rectifier will be connected.

4.1 Input and output location

Originally, the protective circuit of the initial circuit was supposed to be reused with the upgraded rectifier circuit. However, this task was requiring meticulous investigations and thus more time. Therefore, it was more convenient to re-design the whole unit control and keep the valve circuit intact. As a result, the entire valve system was disconnected so that if the upgraded system fails to operate, the initial electronic unit will still be able to operate the plant. The first approach was to determine the input and output connections of the circuit.



<u>Figure 4.1: External wiring connection of the dynamometer</u>

(Dynamometer handbook)

Figure 4.1 illustrates the connections between the dynamometer bed plate connector block and the electronic input panel. As depicted, none of the dynamometer bed plate connections are well defined. However, it can be seen that the dynamometer is connected to the electronic circuit via six input or output connections.

The dynamometer must be protected against over heating. In the cooling system located on the dynamometer side, is embedded a water pressure switch which senses the water pressure. If the water pressure is not sufficient the switch opens a protective circuit which shuts down the engine coupled to the dynamometer. Consequently, there must be a signal from the dynamometer to indicate low water pressure level.

Similarly, the dynamometer has to be protected against over speeding. As explained in the handbook, if the dynamometer speed rises above a preset value the system will also shuts down automatically. Consequently, an output signal from the tacho generator which is located on the dynamometer side must be fed to the control unit to detect when the engine speed goes above a speed limit.

Finally, the dynamometer field coil has to be roused to generate the primary magnetic field for braking process to occur. So, there must be an input signal from the circuit that regulates the amount of current going through the coil.

4.2 Preliminary tests

The dynamometer bed plate connector block contains four outputs and one input connection describe as C1, C2, A2, A1, W2, W1.

The information contained within the handbook does not define any of these connections; subsequently assumptions were made before implementing tests on the dynamometer.

At first, connection C1 and C2 were assumed to refer to the coil connection and therefore enables a signal to go from the electronic circuit to the field coil. Then, it was assumed that connection W1 and W2 were assumed to refer to the water pressure switch located within the dynamometer. And finally, connection A1 and A2 were assumed to be the analogue signal generated by the tacho generator to prevent the engine to over speed.

Connection IG.1, IG.2, and IG.3 are defined as the engine ignition connection and are used to safeguard the engine in case of overspending, or failure of water or electricity supplies. The main power supply is defined by the L and N connections to operate the whole system.

To verify the assumptions about connections C1, C2, A2, A1, W2, W1, a series of tests were implemented on the dynamometer bed plate connections.

- Test at terminals C1and C2

The input signal of the excited coil must be a rectified version of the main source voltage. The best approach to ensure that C1 and C2 are the dynamometer coil input connections a digital oscilloscope was connected across them. Figure 4.2 illustrates the signal obtain across these connections.

As depicted, the signal is half rectified and therefore must be the output of the valve rectifier. As a result, C1 and C2 are defined to be the dynamometer coil connection.

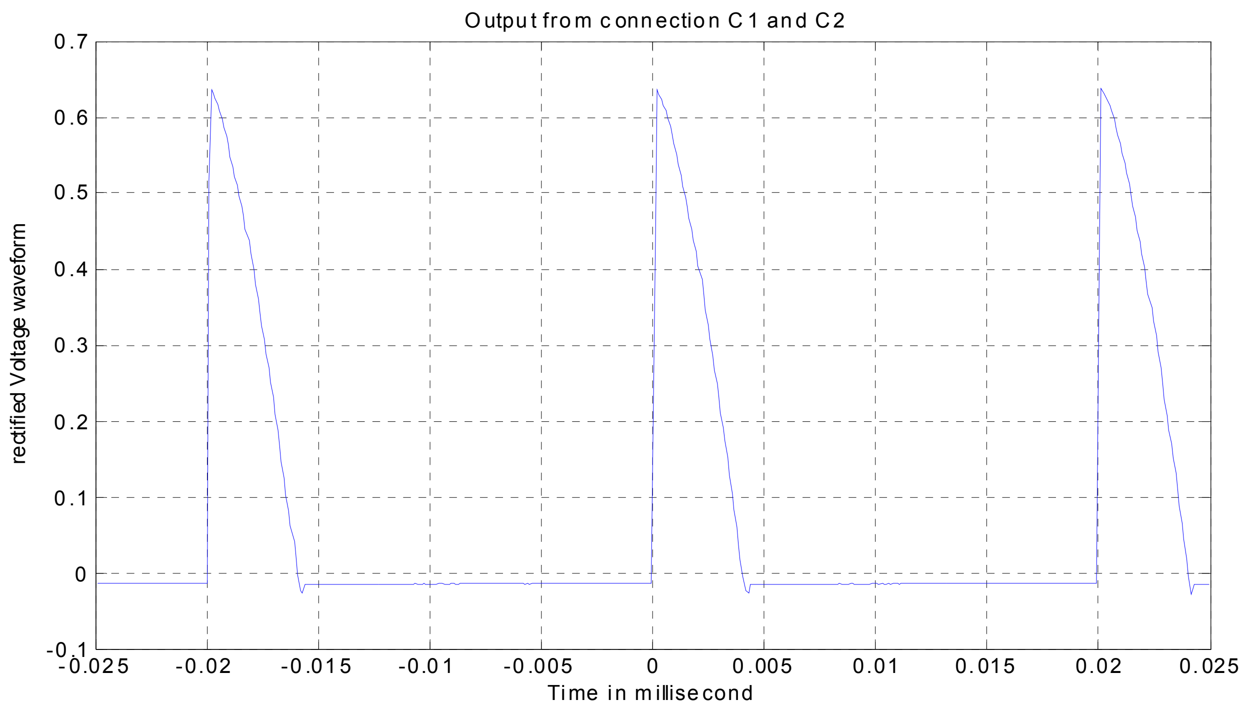


Figure 4.2: Signal obtained across connection C1 and C2

- Test at terminals W1 and W2

As explained before, W1 and W2 are assumed to be the water pressure switch connection of the protective circuit. Consequently, these connections must be connected at both ends of the switch represented in figure 5.1.

A perfect switch, by definition, will have 0 Ω when closed and it will have infinite resistance when opened. To check the resistance between these two connections, an ammeter was connected across them.

The result obtained demonstrated that when there is not water flowing within the cooling system, the resistance across W1 and W2 is infinite. On the contrary, when the water tape is open, the resistance is approximately equal to 0.3 Ω. This test has proven that connection W1 and W2 are the water pressure switch connection.

- Test at terminals A1 and A2

The system uses an analogue tachometer mounted on the dynamometer shaft. The device generates an output voltage that is proportional to the rotational speed.

To prove that A1 and A2 are the tachometer outputs, a digital oscilloscope was connected across these connections while the system was running. As assumed, when the speed was increased or decreased the signal amplitude and frequencies were changing with respect to the engine speed. Figure 4.3 shows the output of the tacho generator at a certain speed.

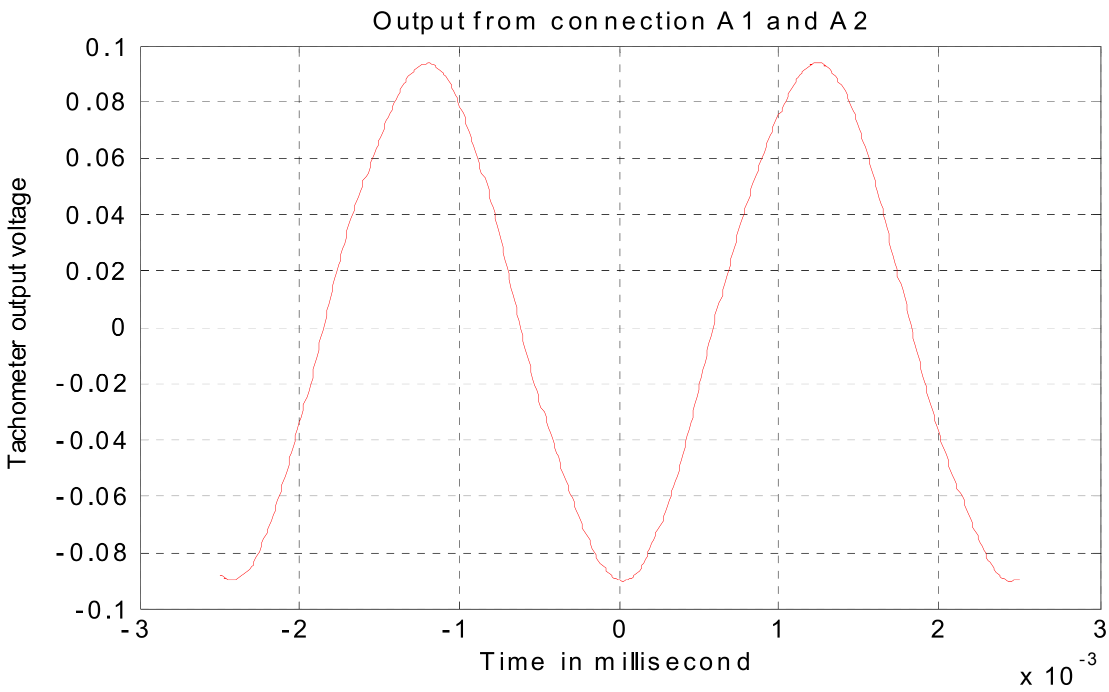


Figure 4.3: Signal obtain across connection A1 and A2

To confirm that the voltage was changing with respect to speed, the proportionality between speed and amplitude was also checked. When the system was running, the voltage RMS and speed reading were proceed and stored in table 4.1.

Table 4.1: Tacho generator output voltage at a certain speed

Speed RPM	VOLTAGE RMS
1000	20.9
1500	29.6
2000	38.9
2500	49.6
3000	58.8
3500	62.3

The following figure illustrates the proportional relationship between speed and the voltage.

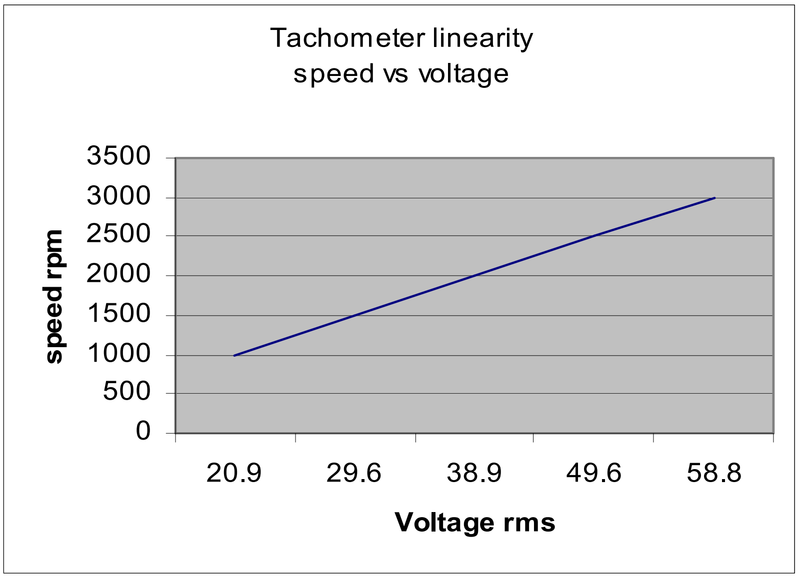


Figure 4.4: Linearity between the output voltage and speed

CHAPTER 5 – PROTECTIVE SYSTEM

Protection of the plant while it is operating is essential. The whole plant has to be protected against over speeding and overheating. At the same time, the user must be safe and has to be protected against any independent emergency. This chapter explains the use of a protective circuit and briefly describes the protective system used with the valve rectifier. Following that, it gives a description of the selected devices used for protection.

5.1 The existing protection system

The circuit depicted in figure 5.1 represents the actual protective circuit that safeguards the engine and the dynamometer in the event of water failure, over speeding or failure of the power supply.

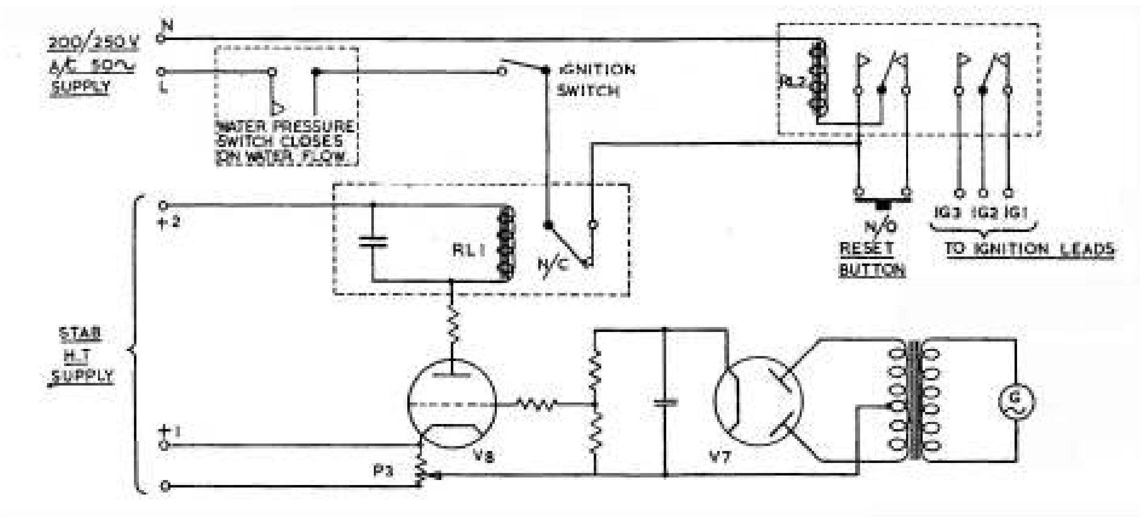


Figure 5.1: Existing protective circuit

(Dynamometer handbook)

5.1.1 The water pressure and ignition switches

- The water pressure switch

Cooling the dynamometer inner rings is essential to safeguard the dynamometer because considerable damage would be done if the instrument overheated. The heat generated by the induced current would melt the stator inner rings if they are not cooled properly.

As explained in the dynamometer handbook, each brake power absorbed generates 42.4 B.Th.U per minute, nearly all of which passes into the cooling water. Consequently, the water pressure must be sufficient to ensure the temperature of the stator inner rings does not rise above 140 degrees Celsius.

To sense the water pressure in the cooling system, a specific protective device is used. It is referred in to the handbook as the water pressure switch. The switch is embedded within the dynamometer cooling system and is connected to the electronic unit by means of the connections W1 and W2. When water is running through the dynamometer with enough pressure, the water pressure switch closes a protective circuit so that the system is safe to run. On the contrary, if the water pressure is not sufficient to cool the inner rings, the switch opens the protective circuit so that the system is shut down or cannot start.

- The ignition switch

This ignition switch is a manually-operated switch and has to be closed for the combustion engine to start. The main purpose of this switch, however, is to safeguard the system or the user in the event of an independent emergency.

5.1.2 The connections of the coil ignition engine

IG.1, IG.2 and IG.3 are the three terminals from the electronic input panel connected with the engine ignition system. The Low Tension connections of the coil ignition engine are connected in series with terminal IG.1, IG.2 and IG.3. These terminals are connected to the second 'change-over contact' of a double pole double throw relay as depicted in figure 5.2.

To stop the engine when a fault occurs, the change over contact has to be on IG.1 and IG.2. For the engine to start, IG.2 and IG.3 must be connected. The Double Pole Change Over (D.P.C.O) relay has two rows of change-over terminals and is actuated by a single coil.

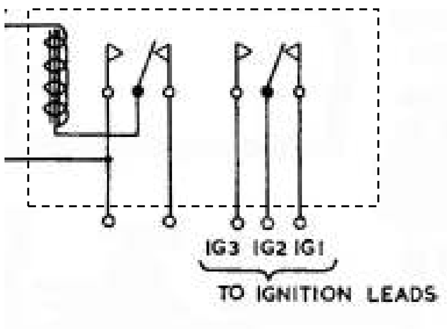


Figure 5.2: Double Pole Double Throw relay (DPDT)

(Handbook, 1881)

5.1.3 Resetting the DPCO relay

To reset the relay, a momentary push button switch is connected to the first change-over contact of the relay. Referring to figure 5.1, if the water switch, the ignition switch and the RL1 internal switch are closed, then by pressing and depressing the reset button the relay becomes energized, so that contacts IG.2 becomes connected to IG.3.

As a result, the engine is ready to be started and the whole system is safe to operate. For the engine to start, the entire set of switches that constitute the protection system have to be closed. If any of the switches open while the system operates the engine is turned off automatically. For example, if the water pressure is insufficient, the water pressure switch will open. Consequently, the coil of the relay will be de- energized and the relay will return to its initial state where IG.2 is connected to IG.1.

5.1.3 Over speed control

The function of the first relay RL1, represented in figure 5.2, is to stop the prime mover if the load generated by the dynamometer fails. When the load fails it is commonly due to either a failure of the main supply or a fault occurring within the excitation unit. If a sudden failure of the load occurs, the speed of the engine will rise so quickly that considerable damages would occur to the prime mover.

In figure 5.1, valve V8 is biased off by adjusting the potentiometer P3. The position of P3 determines the speed at which the plant should shut down. V8 will remain biased off until the rectified signal from the tacho generator exceeds the bias condition. In the case that the rectified D.C signal exceeds the over speed cut out adjustor limit, V8 will allow current to pass and will energised the coil of RL1. As a result, Relay one open the protective circuit and de-energises Relay two (RL2) which closes contacts IG.1 and IG2 (Dynamometer handbook).

5.2 Upgraded protection system

An upgraded version of the initial protective system has been designed and tested onto the dynamometer. The circuit uses the latest technology available from Farnell's catalogue 2005.

The circuit guarantees that the engine stops automatically in the event of insufficient water pressure, over speeding or a fault occurring in the excitation unit. For design simplicity and convenience, the water pressure sensor has been re-used.

5.2.2 Over speeding protection device

As explained earlier, the circuit must prevent over speeding for engine protection. When the speed of the dynamometer shaft rises above a preset value, the prime mover must stop. The most suitable device for this operation is the Multifunction Voltage Relay also called the M3MVR. As a result, the section of the initial protective circuit represented in figure 5.3 is replaced by using only this device.

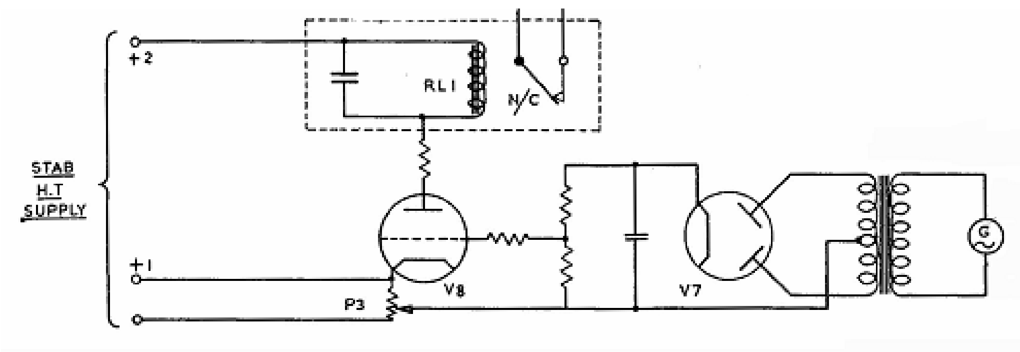
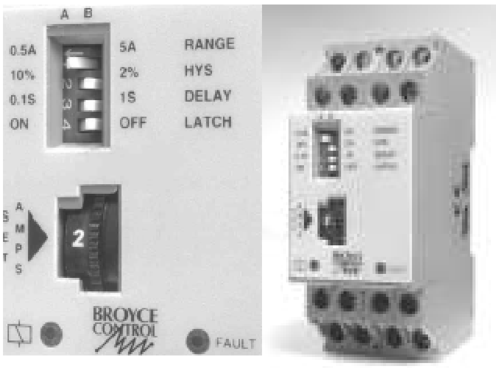


Figure 5.3: Over speed protection used with initial design

(Dynamometer handbook)

The M3MVR automatically adjusts for AC or DC supply. The relay can be used for either under voltage monitoring or over voltage monitoring. For this application the device is used for over voltage monitoring. The tripping mode of the relay must be selected at the time of installation by means of a rear mounted switch. Figure 5.4 illustrates the M3MVR relay.



<u>Figure 5.4: M3MVR and front panel</u>

(Source: http://www.broycecontrol.com)

For this application, the M3MVR is used to track if the voltage output from the tacho generator goes above a preset voltage. As soon as the M3MVR receives an analogue signal with a peak value above the limit, the internal switch opens and thus opens the protective circuit, stopping the engine.

When the relay has triggered it can be reset by either momentarily removing the power supply or turning the latch switch to the off position.

The main advantage offered by this relay is that if a spike is generated by the tacho generator the relay will not respond to this high voltage. In order for the relay to trip, the analogue signal should stay above the preset over voltage limit for a pre-defined interval of time. The time (t), in figure 5.5 represents the tripping time delay. The relay can be set to delay tripping, for 100 ms or 1 second, using the front mounted delay switch.

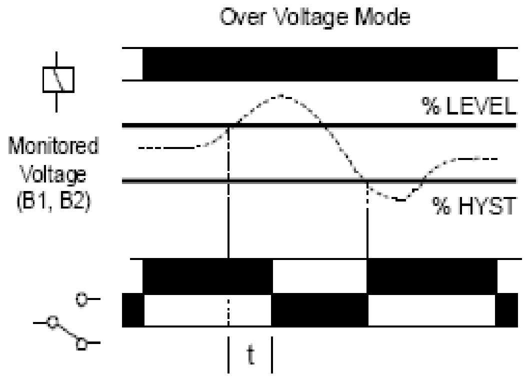


Figure 5.5: Timing diagram for over voltage monitoring

(Source: http://www.broycecontrol.com)

If the relay is monitoring close to its tripping point, it might continuously pull in and drop out as the voltage continually passes through the set point. To overcome this problem, an adjustable hysteresis level has been incorporated to the relay. This causes the relay to re-energise at a point which is at either 2% or 10% below the set point level. The choice of hysteresis level can be made using the front mounted switch (see figure 5.4). The M3MVR is able to monitor two different ranges of voltages.

M3MVR technical specifications:

Supply voltage (nominal): 18 – 240 V AC 50/60 Hz

Min./max limits : 15 – 265 V AC 48/63 Hz

Power consumption: 3 VA

Output contact ratings: 8 A, 250V AC

Input impedance: 10 MΩ

Monitoring ranges:

Range 1	1 to 26.5 V AC
Range 2	10 to 265 V AC

Maximum input voltage: 1000V

Figure 5.6 represents the section of the upgraded protection circuit that will protect the engine against over speeding.

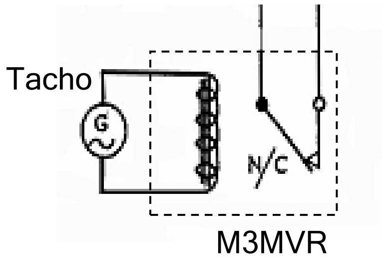


Figure 5.6: M3MVR

5.2.3 Resetting the initial state of the circuit

The most suitable relay to control the state of the engine and thus guarantee protection of the whole system is the DPCO-5532, illustrated in figure 5.7. This miniature general purpose relay is called an "ice cube" relay in reference to its transparent enclosure and size. The transparency allows inspection of the contacts, coil, and swing arms for evidence of overheating.

Figure 5.7: DPCO-5532

Contacts specifications:

Contact configuration: 2 Change over, DPDT.
Rated current/Maximum peak current: 10 A.
Rated voltage/Maximum switching voltage: 250 V AC.

Coil specification:

Voltage, coil AC nominal: 230 V.

Coil resistance: 17 Ω.

This relay is the core of the protection system. When its coil is energised, it maintains circuit protection, and when the coil is de-energised the relay shuts down the engine by means of IG.1, IG.2 and IG.3.

5.2.4 Protective circuit configuration

While designing the new protective circuit, it was more convenient to refer most of the design to the old circuit. The upgraded protective system is depicted in figure 5.8. The water switch closes as soon as there is enough water pressure in the cooling system. When the ignition switch is manually closed, the system is ready to operate and an indicator indicates that the plant is ready. However, before starting the engine the reset button has to be pressed and depressed so that the relay "DPCO – 5532" becomes energized and closes contacts IG.2 and IG.3.

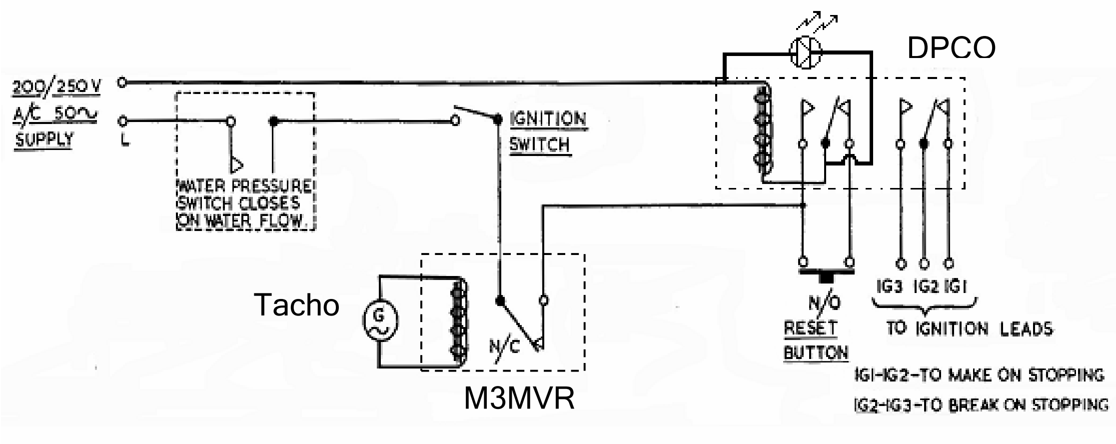


Figure 5.8: Protective circuit

CHAPTER 6 – THE UPGRADED SYSTEM

Upgrading the rectifying system has required a selection of specific devices. This chapter introduces the selected devices used for rectification and describes the operation of the upgraded system.

6.1 The half control bridge rectifier

6.1.1 AC to DC converter

Silicon controlled rectifiers are available in a variety of integrated circuit packages which have different number of pins. After a meticulous search for the most suitable device, the integrated power circuits P102W was selected to convert the AC source to DC. This device consists of power thyristors and power diodes configured in a single package as illustrated in figure 6.1. As depicted in the following figure, the module is mounted on an alumina substrate to provide a completely isolated assembly.

Figure 6.1: P102 W module

(Source: http:// www.farnell.com)

Figure 6.2 illustrates the internal configuration of the module and shows that the module has a free wheeling diode connected in parallel to the load of the module.

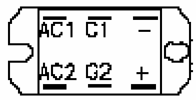
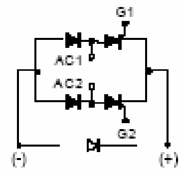
Terminal Positions	
Schematic diagram diagram	

Figure 6.2: Internal bridge rectifier configuration

(Source: http://www.irf.com)

Table 6.1 details all the major ratings and characteristics of the P102W module.

Table 6.1: P102W ratings and characteristics

(Source: http://www.irf.com)

Parameters		P100	Units
I_D		25	A
	@T_C	85	°C
I_{FSM}	@50Hz	357	A
	@60Hz	375	A
I^2t	@50Hz	637	A^2s
	@60Hz	580	A^2s
$I^2\sqrt{t}$		6365	$A^2\sqrt{s}$
V_{RRM}		400 to 1200	V
V_{INS}		2500	V
T_J		- 40 to 125	°C

- Heat sink

When the internal diodes or thyristors are forward biased, there is a current flowing through it, as well as a voltage across it. Semi conductor power losses are dissipated in the form of heat, which must be transferred away from the switching junction (William1992). An excessive amount of heat can be damaging or destructive to the module. In order to control the module temperature, the device is mounted on a specific heat sink which ensures a good thermal equilibrium between the junction temperature and the ambient temperature. The following table details the thermal and mechanical specification of the rectifier module.

Table 6.2: Thermal and mechanical specification of the P102W module.

(Source: http://www.irf.com , 2006)

	Parameter	P100	Units	Conditions
T_J	Max. operating temperature range	-40 to 125	°C	
T_{stg}	Max. storage temperature range	-40 to 125		
R_{thJC}	Max. thermal resistance, junction to case	2.24	K/W	DC operation per junction
R_{thCS}	Max. thermal resistance, case to heatsink	0.10	K/W	Mounting surface, smooth and greased
T	Mounting torque, base to heatsink	4	Nm	A mounting compound is recommended and the torque should be checked after a period of 3 hours to allow for the spread of the compound
wt	Approximate weight	58 (2.0)	g (oz)	

The thermal resistance of the heat sink depends on its size, its construction and its orientation. Figure 6.3 illustrates the heat sink where the rectifying module is mounted.

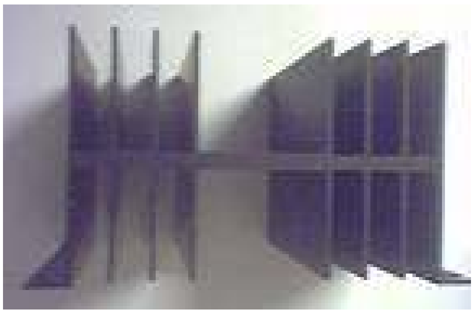


Figure 6.3: Heat sink

The heats sink has a thermal resistance of 0.85°C/W and is made of aluminium. It utilise finned surface area on both side of the module mounting surface in order to provide maximum heat dissipation.

6.1.2 Firing module for the P102W

The selected trigger module illustrated in figure 6.4 uses variable phase angle control with adjustable signal matching, integral current limit input and adjustable soft start.

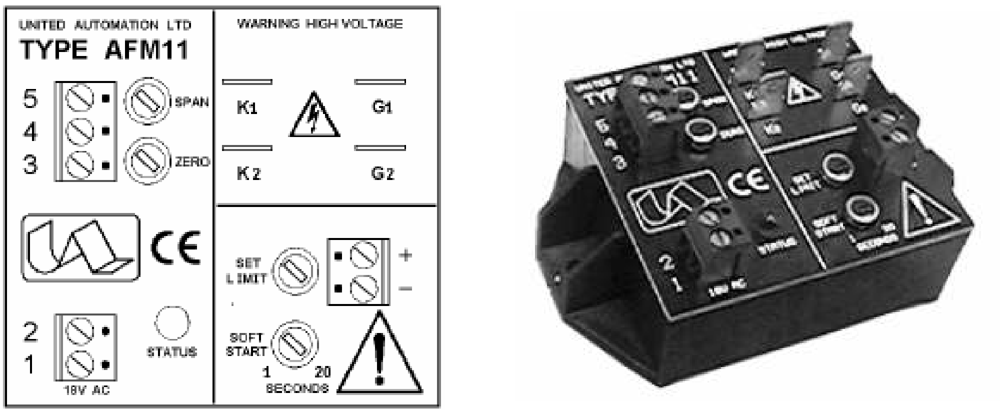


Figure 6.4: AFM-11

(Source: http://www.powercontrollers.net/components/firing_circuit)

As depicted in figure 6.5, the module offers four different ways to control the phase angle generated by the firing module. Control can be achieved via an input signal, a relay, a manual potentiometer or a DC input signal. The module offers an adjustable current limit option that can be used when designing the close loop system.

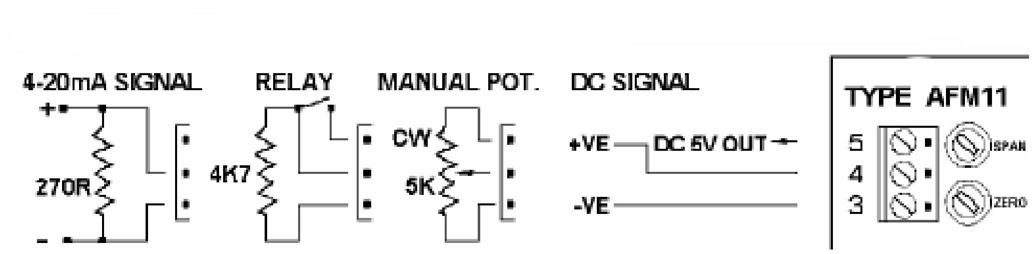


Figure 6.5: Control option for terminal 5,4 and 3

(Farnell, 2005)

- The control potentiometer

Although, there are different methods available to control the angle of conduction, the use of a manual potentiometer is one of the most suitable options to manually control the load generated by the dynamometer. A 5kΩ potentiometer illustrated in figure 6.6 is connected to the firing module.

Figure 6.6: 5 kΩ potentiometer

(Source: http://www.farnellinone.com)

- Supply step down transformer

In order to operate the triggering module and the multifunction relay, the mains source has to be step down to 24 V AC. The transformer illustrated in figure 6.4 is a step down transformer that converts 230 V AC to 24 V AC. As illustrated in picture 6.7 the transformer provides two secondary voltages.

Figure 6.7: Transformer

(Source: http://www.farnellinone.com)

Transformer characteristics :

Power, AC: 12VA
Voltages, secondary: 0-24, 0-24
Voltage, single primary: 230 V
Power, per secondary winding: 6VA
Regulation: 12%

(Appendix E details the cost of these devices)

6.2 Upgraded system: Manual torque control

As explained earlier, the new control unit must supply the dynamometer field coil with an adjustable DC source. However, the whole system has to be protected and safe to use.

The upgraded system consists of the protection circuit and the upgraded rectifier. Figure 6.8 illustrates the block diagram representation of the upgraded system.

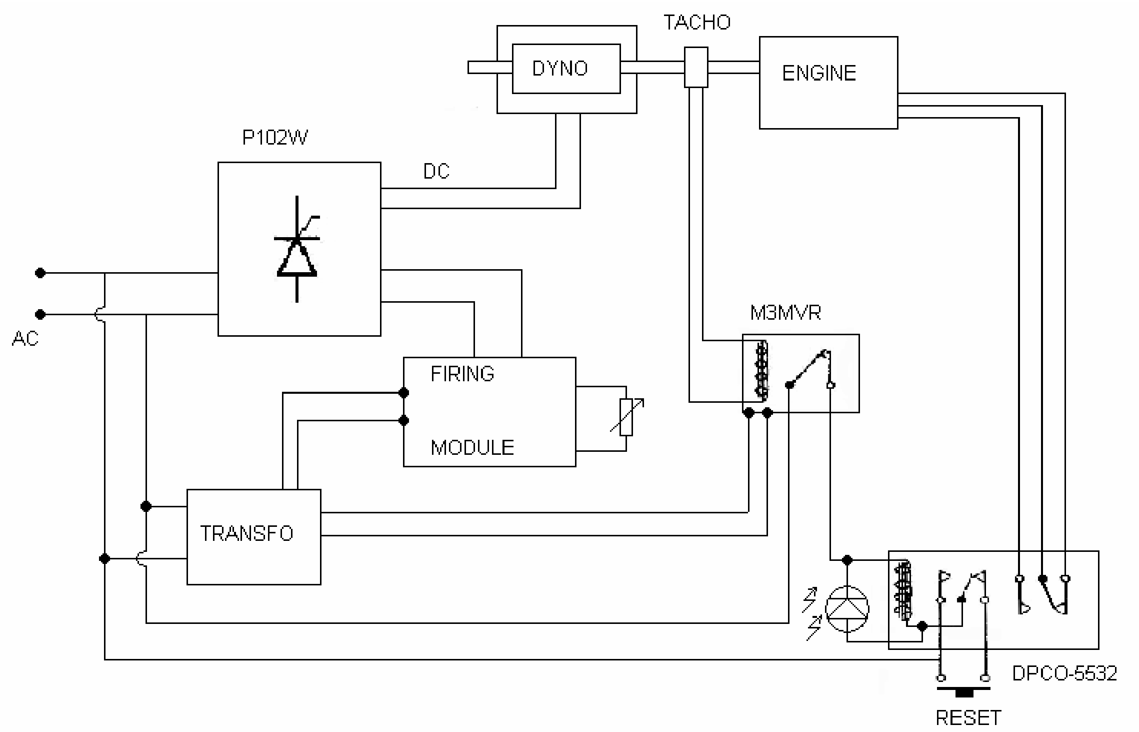


Figure 6.8: Upgraded control unit system

The control potentiometer is connected directly to the firing module to ensure manual load control. Once the potentiometer is set to a certain position, the firing module generates a pulse signal which occurs at a specific delay angle. As a result, the P102W produces a constant level of direct current to the field coil and thus generate a load that will quickly become constant irrespective of further engine speed rise.

The new control unit is connected to the electronic input panel illustrated in Figure 6.9 These connections are located within the initial control desk.

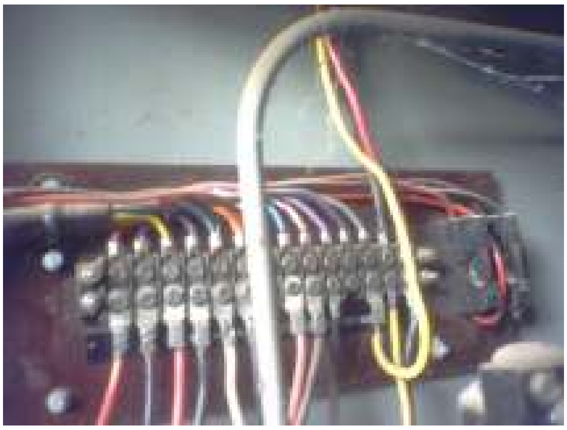


Figure 6.9: Electronic input panel

6.3 Laboratory testing on the upgraded system

Before implementing any testing onto the dynamometer, the new circuit was tested in laboratory to verify if the circuit was working properly. Figure 6.10 illustrates the testing configuration of the upgraded system.

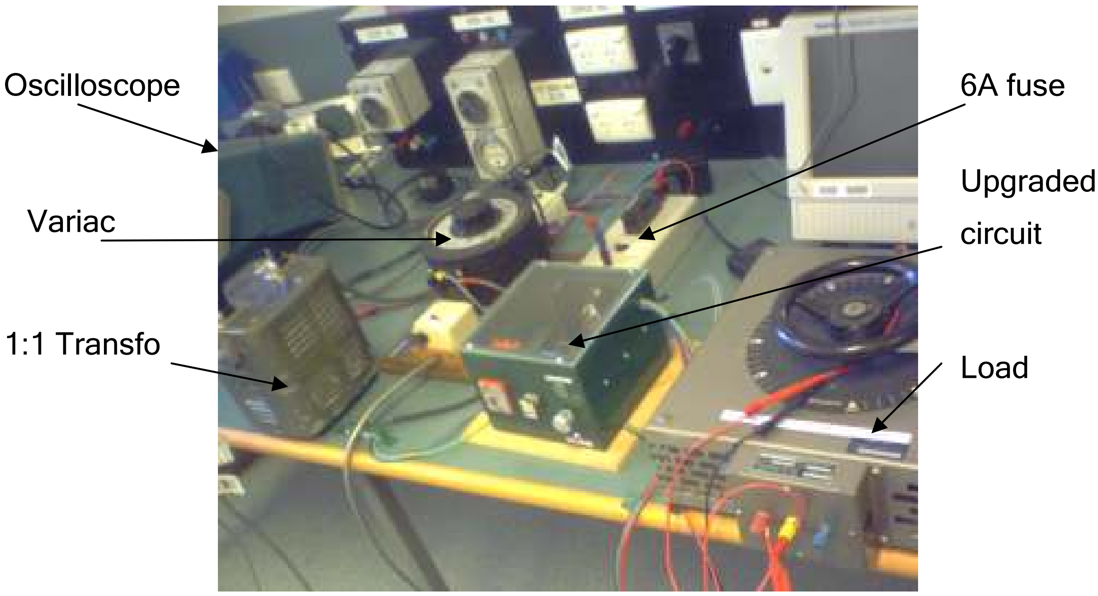


Figure 6.10: Testing configuration of the upgraded system

The first test was performed to verify if rectification was occurring. To replace the dynamometer coil, an inductive load was connected in series with a resistive load. The output wave form of the source voltage and the rectified signal was obtained via a digital oscilloscope (Tektronix TDS 420A). Figure 6.11 illustrates the rectifier output at a specific angle of conduction.

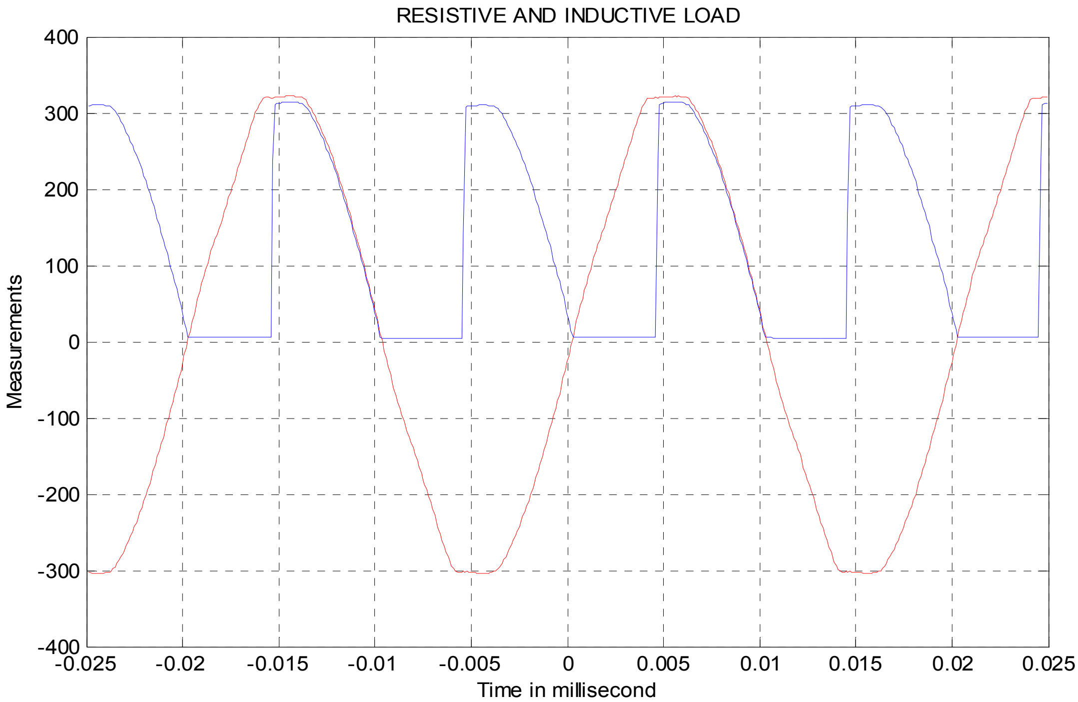


Figure 6.11: Upgraded rectifier output

The second series of tests was organised to check the reset condition of the protective circuit and if the system shuts down in the event of over speeding. Figure 6.12 illustrate the circuit configuration tested within the laboratory.

The reset condition of the protective circuit has been verified by ensuring that no voltage was across the DPCO coil before the reset button was pressed. Thus, when the reset button was pressed and depressed, 230 V AC appeared through the same coil and a red lamp lights to indicate that the plant is ready. The reset option works as expected so further testings were carried out to verify over speeding protection.

The reset button has been pressed and depressed so that the system is now protected. If the internal switch of the M3MVR opens, the magnetic field of the DPCO coil collapses and thus connection IG.2 connects to IG.1in order to shut down the engine.

To ensure full system protection against over speeding within the laboratory, the main AC source was connected to a variac to obtain variable AC source that will replace the tacho generator output in the laboratory. The signal from the variac was fed to the monitored input connection of the M3MVR relay with the intention of tracking if the voltage goes above a predefined value. When the monitored signal goes above the voltage limit, the internal switch of the relay opens the protective circuit, so that the DPCO relay switches back to its initial state and thus stop the engine.

To guarantee that the DPCO had switched back to its initial state, the resistance across the second internal switch of the DPCO relay was measured via an ampere meter. When the whole system is protected, the resistance across IG2 and IG1 is very high. On the other hand, when the system is not protected or when a fault occurs, the resistance across these terminals is very low because IG.2 connects back to IG.1.

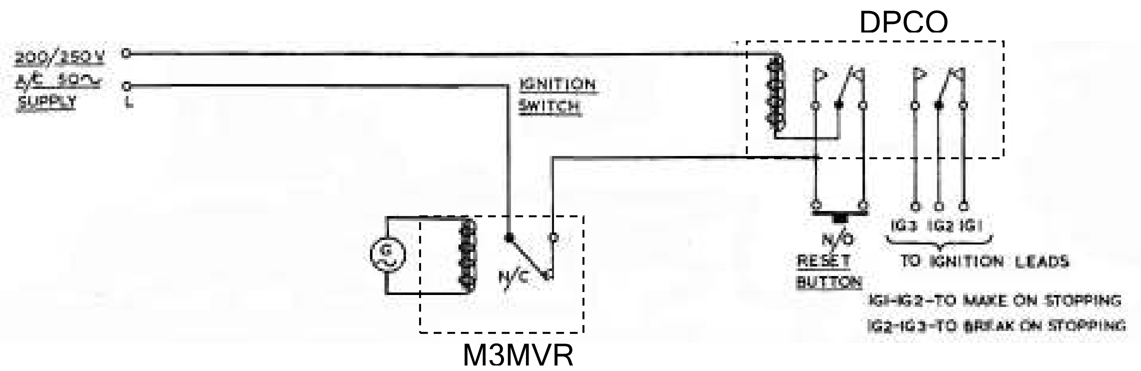


Figure 6.12: Protection circuit tested within the laboratory

6.4 The new control unit of the Heenan dynamometer

The new control gear is mounted within a metallic box which may be situated at any convenient distance from the dynamometer. Figure 6.13 represents the upgraded control unit for the Heenan dynamometer. The box is earthed to provide an alternative path for a fault current so that the user is protected. All internal connections are covered with heat shrink so that the user is safe to touch any internal wires however this is not recommended. Perspex has been used on the top of the box for educational purpose and at the same time to see the status of the firing module.

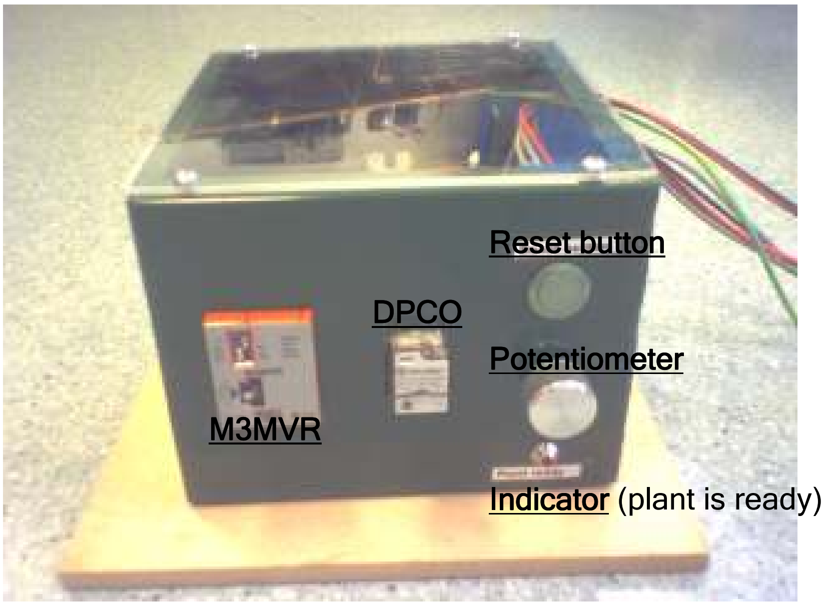


Figure 6.13: Upgraded control unit

As depicted in the above figure, the M3MVR and the DPCO are located on the front of the control box. This configuration allows any user to select the controlling options offered by the M3MVR and at the same time it allows the control of the internal contact of DPCO relay. Both relay are mounted on a DIN rail from inside.

(Appendix F details the design of the control unit box)

6.5 Test on the dynamometer

Testing the upgraded control unit on the dynamometer was not achieved because the contact ratings of the DPCO relay were inappropriate for this application. While connecting the upgraded control unit to the dynamometer, it was realised that the actual relay (RL2) connected to the ignition coil was extremely big compare to the DPCO relay. As a result, it was assumed that the new relay will not withstand the inductive current coming from the coil.

The coil of the engine is operated by a 20 V DC battery so that when connection IG.2 is connected to IG.3 the coil current is flowing trough the inductor. Therefore, a magnetic field exists in the region surrounding the inductor. The energy transferred form the DC supply is now stored in the inductor. Consequently, when the switch opens the impedance across it increase and consequently a very high voltage is required across the switch if current is to continue to flow trough it. As a result damage will be caused to the internal switch of the under rated relay.

CHAPTER 7 – OPEN LOOP AND CLOSE LOOP

The valve control system has two mode of operation. These two modes of operation are selected by means of an external selector switch located on the control desk. When the switch selects "Governed engines" operating mode, the dynamometer acts as an open loop system and when the switch selects "Ungoverned engines", the control unit operated as a close loop system. This chapter describes the open loop configuration of the upgraded control unit and briefly explains how feed back control can be achieved.

7.1 The open loop systems

An open loop system is a control system that does not use its output to correct the process of the system. The system is given a predefined input signal and the output signal must behave in a predefined manner (Nise 2003). Thus, the open loop controller of the dynamometer system will essentially be a potentiometer that will generate different level of current to the dynamometer's coil.

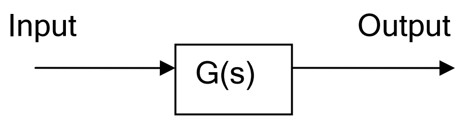


Figure 7.1 Open loop system

The design of the open loop of the dynamometer system contains a half controlled bridge rectifier, a firing module and its potentiometer. The bridge rectifier is the input transducer that converts the main AC source to a DC source. The firing module is the device that generates the triggering gate current at a specific time. By shifting the firing point, by means of the potentiometer, the half controlled bridge rectifier will produce different level of exciting current to the dynamometer's coil. Consequently, the load imposed to the coupled engine will be different at different potentiometer position. While operating with the open loop system, the DC current flowing in the dynamometer coil is constant irrespective of the dynamometer's speed.

7.2 The close loop system

Systems that use a feedback signal are called closed-loop control systems. The reason for using feedback control with the dynamometer is to provide engine speed stabilisation. In cases such as the testing of an internal combustion engine, speed stabilisation of the engine is necessary to measure many engine performances at a specific speed. For example, when designing an engine it is relevant to know how much fuels the engine consumes at a specific speed. Similarly, using the dynamometer to stabilise the speed of the engine facilitates the tunning of the engine.

To maintain the speed of the engine, the load of the dynamometer must be adjusted whenever the engine speed is changing. As explained earlier, the load generated by the dynamometer is proportional to the amount of current flowing through the field coil. As a result, speed control can be achieved by varying the amount of current generated by the AC to DC converter.

In order to adjust the DC output of the converter, the conduction angle has to be varied automatically in response to any change of the engine speed. In this case, the feedback signal is used to adjust the output of the driven system. The motor speed is measured by means of the tacho generator and the signal is fed back to a comparator. The second input signal of the comparator is called the reference speed signal and is generated by means of a controlling potentiometer.

The comparator also known as 'error amplifier' compares the two signals and produces an output signal "the error signal". This signal is dependent on the difference between the speed reference signal and the feed back signal. A controller processes this signal in order to reduce the error. The output of the controller is then processed by the firing module which generates the required delay angle. As a result, for any change of the engine speed, there will be a change in the dynamometer load.

For this application, the most suitable controller would be a proportional plus integral plus derivative controller (PID). The input of the PID controller is the difference between the fed back signal and the reference signal. If the feedback signal is lower than the reference signal, it means that the engine is running below the reference speed. Consequently, the load generated by the dynamometer has to be reduced and vice versa. Figure 7.2 represents the close loop system configuration in order to achieve the engine speed stabilisation.

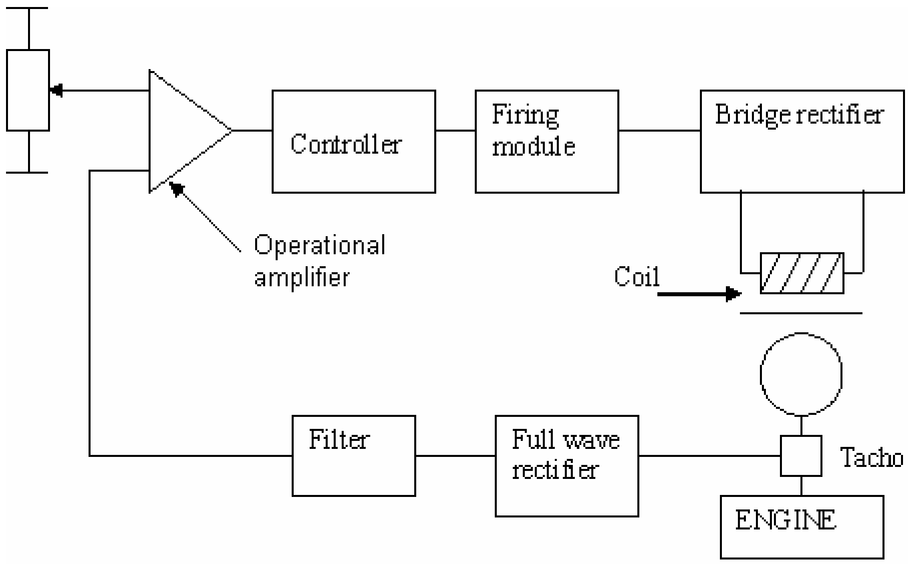


Figure 7.2: Block diagram the close loop system

7.2.1 The reference signal

The reference signal can be obtained by using a potentiometer connected to the five volts DC output from the firing module. Figure 7.3 shows the feedback control configuration of the triggering module.

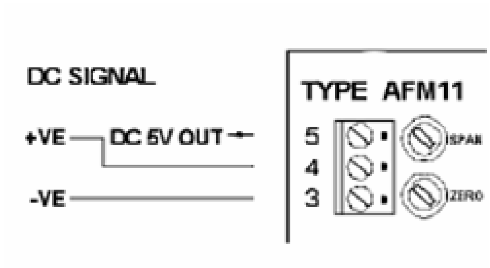


Figure 7.3: Triggering module output

In order to match both signals to the same voltage range (0 - 5 volts), the output voltage of the tacho generator will have to be stepped down so that the feed back signal will only varies between 0 and 5 volts.

7.2.2 The feed back signal

The tacho generator converts the rotational speed of the shaft into an analogue voltage signal that is processed and used for speed control. However, before comparing the tacho generator output against the speed reference signal, the feed back signal must be rectified. The analogue signal can be fed into a full bridge rectifier and then a low pass filter to obtain a suitable DC feed back signal.

Low pass filter transfer function is defined in equation:

$$\frac{Vout}{Vin} = \frac{1}{1 + sCR} \quad (7.1)$$

7.2.3 The difference amplifier

The reference signal and the feed back signal are compared to obtain the error signal that will drive the controller. The most suitable amplifier configuration for this task is the difference amplifier.

This op amp configuration amplifies the difference between two input voltages however the ratio of R1/R2 must be equal to the ratio R3/R4 to produce the required error voltage. Equation 7.2 expresses output voltage in terms of R1, R2, V2 and V1.

$$Vout = \frac{R2}{R1} \times (V2 - V1) \tag{7.2}$$

Vout is referred as the error signal. Figure 7.4 gives the basic circuit configuration of a differential amplifier.

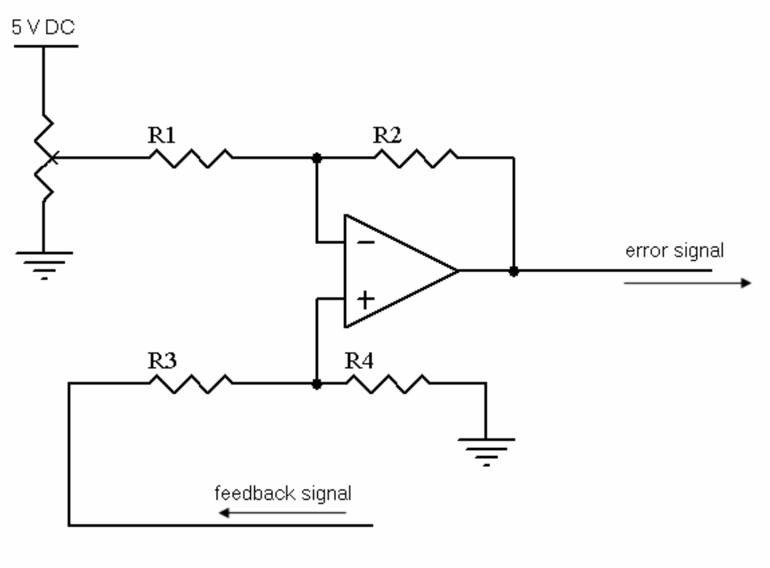


Figure 7.4: Differential amplifier configuration

7.2.4 PID Controller

The PID controller is the widely used in process control. PID refers to Proportional-Integral-Derivative, referring to the three terms operating on the error signal to produce a control signal. The control signal is given by equation 7.2

$$V_{control}(t) = k_p e(t) + k_i \int e(t)dt + k_d \frac{de(t)}{dt} \qquad (7.2)$$

Figure 7.5 illustrate the use of a PID controller in a feedback control system.

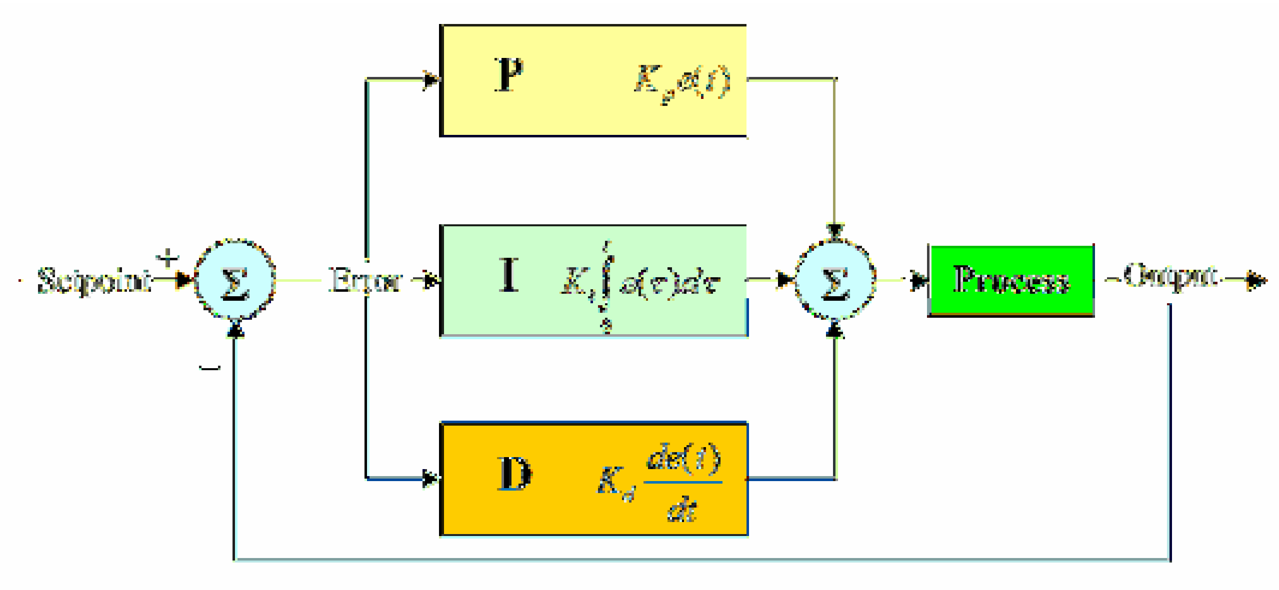


Figure 7.5: PID controller

(Source: http://en.wikipedia.org/wiki/Image)

With the proportional component, the error is multiplied by a constant in order to control the actual error signal. At the same time, the error signal is integrated over a period of time and then multiplied by a constant in order for the system to correct previous error. Finally, the derivative term controls the response to a change in the system.

With the derivative term the controller can anticipate what action is needed by estimating the rate of change of the error signal (Parr 1996). As a result, when the error signal is changing rapidly, the controller adds more corrective actions to the plant.

CHAPTER 8 – DISCUSION AND CONCLUSION

8.1 Achievement of Objectives

The aim of this project was to upgrade the existing eddy-current dynamometer by replacing its current valve operated DC source with a power electronic system. Most of the objectives put forward at the start of this project were fulfilled, however, some of them changed during the year.

The protective circuit of the initial circuit was supposed to be re-used with the upgraded system. However, with a meticulous analysis of the circuit configuration it became apparent that this option was going to be time consuming and would result in a deterioration of the initial control unit. As a result, it was preferable to disconnect the entire system and design the whole circuit with updated devices.

The first new objective was to upgrade the protection circuit to ensure the safeguards of the dynamometer. As a result, an updated version of the initial protection circuit has been designed and tested in the laboratory. The new protection circuit works perfectly in the laboratory but has not been tested onto the dynamometer because the selected DPCO relay has been under-rated.

As well as this new objective, only a brief description of the closed loop control configuration has been investigated so as to introduce the concept of engine speed stabilisation to a future student.

8.2 Further Work

It was realised that the selected relay which is connected to the ignition coil was not suitable for this application. Two propositions were offered to solve this problem.

The first was to use the initial protection circuit with the upgraded rectifier.This option is time consuming and will degrade the initial circuit ,however, is a realisable option.

The second option was to run the valve rectifier circuit and sense the current from the ignition coil while the engine was turned off by means of RL2 (see figure 5.1). By knowing the peak value of inductive current while the magnetic field of the coil collapses, a well rated diode can be selected and then connected in parallel to the ignition coil. This diode will act as a free wheeling diode so that the inductive current will remain within the coil.

Chapter seven introduces the closed loop configuration of the system and briefly explains how speed stabilisation can be achieved. The feed back control system requires further analysis and more investigation of system stabilisation. As a result, this project leads to the design of the closed loop control system.

With further work, the upgraded control unit will provide two different modes of operation. The first mode of operation, presented in this study, provides manual load control in order to test and record engine performance. The second mode of operation will enable engine speed stabilisation.

In the near future, it will be possible to connect the control unit to a computer in order to acquire digital data. The actual torque measuring apparatus will be replaced by a load cell so that test data can be transmitted to a data acquisition system rather than being recorded manually.

8.3 Conclusion

This study provides a description of the process involved in eddy current braking and more specifically it defines how the Heenan dynamometer braking process occurs. Moreover, the dissertation describes the process of rectification and how it has been achieved in order to generate an adjustable DC source from a single phase AC source. Also, the paper provides a comprehensive chapter on how the dynamometer, the control unit and the engine are protected and gives a description of the protection devices used in the upgraded protective circuit. Following that, a description of the devices selected for half control rectification is given. The final topic briefly describes how engine speed stabilisation can be achieved using the open loop system.

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III APPENDICIES

APPENDIX A – PROJECT SPECIFICATION

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 RESEARCH PROJECT

PROJECT SPECIFICATION

FOR:	**BAVARIN RUDOLPH**
TOPIC:	50KW EDDY CURRENT BRAKING
SUPERVISOR:	Dr Tony AHFOCK
ENROLMENT:	ENG 4111 – S1, D, 2006; ENG 4112 – S2, D, 2006
PROJECT AIM:	The project aim is to upgrade an existing eddy-current dynamometer by replacing its current valve operated DC source with a power electronic system.

PROGRAMME: Issue A, 27 march 2006

1. Research and document the basic principles of the dynamometer.
2. Familiarize with the existing dynamometer.
3. Carry out tests on the existing dynamometer that will help with the design of the new DC supply.
4. Design the new DC supply considering requirements such as open-loop/close-loop speed control option.
5. Construct the DC power supply and test the upgraded system.

For a 'C' grade a good attempt at step (1) to (4) is expected as well as a dissertation of acceptable standard.

For an "A" grade or higher, the requirements are a good attempt at steps (1) to (5) as well as a well written dissertation.

AGREED: ____ (Student)

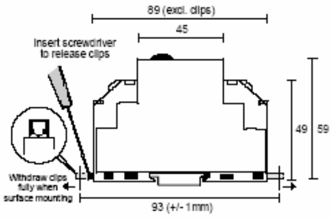
____ (Supervisor)

Date ___/___/ 2006

APPENDIX B – M3MVR DATA SHEET

M3MVR Multifunction Voltage Relay

MOUNTING DETAILS
INSTRUCTIONS DE MONTAGE
MONTAGEAUFÜHRUNGEN
ISTRUZIONI DI MONTAGGIO



Width / largeur / Breite / Largh.. 35 mm (DIN 43880)

- OVER OR UNDER VOLTAGE - SELECTABLE
- LATCHING FACILITY - SELECTABLE
- DELAY FROM FAULT - SELECTABLE
- HYSTERESIS - SELECTABLE
- MULTI RANGE
- MULTI VOLTAGE

• INSTALLATION AND SETTING

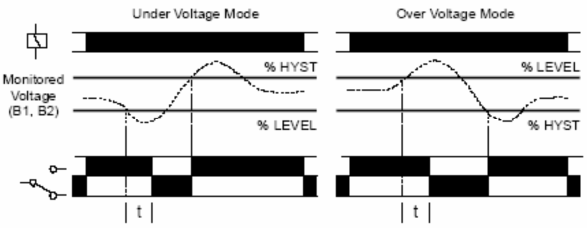
Installation work must be carried out by qualified personnel.

- BEFORE INSTALLATION, ISOLATE THE SUPPLY.
- Connect the unit as shown in the diagram above.
- Select 'over' or 'under' mode on base of unit.
- Select range, delay and hysteresis as required.
- Set trip level.
- Apply power (green LED on, red LED off, contacts 15 and 18 closed).
- Set latching as required.

Troubleshooting

- Check wiring and voltage present.
- Check polarity (for DC supplies only).

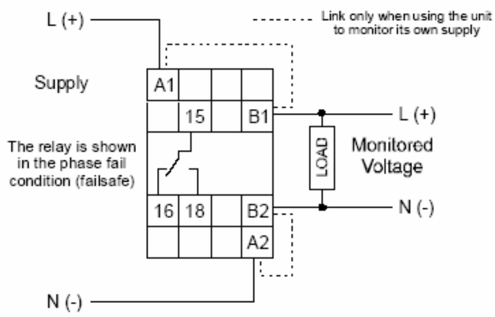
TIMING DIAGRAM
DIAGRAMME DES TEMPS
ZEITDIAGRAMM
DIAGRAMMA TEMPI



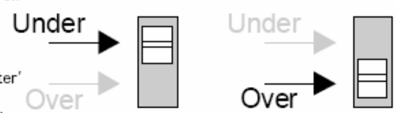
• TECHNICAL SPECIFICATION

Supply voltage U: (AC: 48 - 63Hz)	18 - 240V AC 12 - 240V DC (Galvanic isolated by transformer)
Isolation:	3.75kV (supply to relay contacts)
Power consumption:	< 3VA
Monitoring input / range:	1. 1 - 26.5V AC*/DC 2. 10 - 265V AC*/DC * 48 - 500Hz
Overload:	1kV AC/DC < 60S
Hysteresis:	≈ 2 / 10% (selectable)
Time delay (t): (from fault)	≈ 100mS / 1S (selectable)
Ambient temperature:	-20 to +60°C
Relative humidity:	+95%
Contact rating:	1 x C.O. AC1 250V AC 8A (2000VA) AC15 250V AC 2.5A DC1 25V DC 8A (200W)
Electrical life:	≥ 150,000 (AC1)
Housing:	to UL94 VO
Weight:	≈ 109g
Mounting option:	to BS5584:1978 (EN50 002, DIN 46277-3)
Terminal conductor size:	≤ 2 x 2.5mm² solid / stranded
Approvals:	UL, CUL, CE and C Compliant

CONNECTION DIAGRAM
DIAGRAMME DE CONNECTION
SCHALTBILDANSCHLUSS
DIAGRAMMA DI CONNESSIONE



- Select 'over' or 'under' mode on base of unit.
- Sélectionner le mode 'sous' ou 'sur' la base de l ' unite.
- Betriebsweise 'uber' oder 'unter' als Einheitsbasis wählen.
- Selezionare la modalità 'sovra' o 'sotto' sulla base dell'unità.



The information provided in this literature is believed to be accurate (subject to change without prior notice); however, use of such information shall be entirely at the user's own risk

APPENDIX C – P102W DATA SHEET

Bulletin I27125 rev. A 04/99

International
IOR Rectifier

P100 SERIES

PASSIVATED ASSEMBLED CIRCUIT ELEMENTS

25A

Features

- Glass passivated junctions for greater reliability
- Electrically isolated base plate
- Available up to 1200 V_{RRM}, V_{DRM}
- High dynamic characteristics
- Wide choice of circuit configurations
- Simplified mechanical design and assembly
- UL E78996 approved

Description

The P100 series of Integrated Power Circuits consists of power thyristors and power diodes configured in a single package. With its isolating base plate, mechanical designs are greatly simplified giving advantages of cost reduction and reduced size.
Applications include power supplies, control circuits and battery chargers.

Major Ratings and Characteristics

Parameters		P100	Units
I_D		25	A
	@ T_C	85	°C
I_{FSM}	@50Hz	357	A
	@ 60Hz	375	A
I^2t	@50Hz	637	A^2s
	@ 60Hz	580	A^2s
$I^2\sqrt{t}$		6365	$A^2\sqrt{s}$
V_{RRM}		400 to 1200	V
V_{INS}		2500	V
T_J		- 40 to 125	°C

ELECTRICAL SPECIFICATIONS

Voltage Ratings

Type number	V_{RRM} maximum repetitive peak reverse voltage V	V_{RSM} maximum non-repetitive peak reverse voltage V	V_{DRM} maximum repetitive peak off-state voltage V	I_{RRM} max. @ T_J max. mA
P101, P121, P131	400	500	400	10
P102, P122, P132	600	700	600	
P103, P123, P133	800	900	800	
P104, P124, P134	1000	1100	1000	
P105, P125, P135	1200	1300	1200	

On-state Conduction

	Parameter	P100	Units	Conditions		
I_D	Maximum DC output current	25	A	@ T_C = 85°C, full bridge		
I_{TSM} I_{FSM}	Max. peak one-cycle non-repetitive on-state or forward current	357	A	t = 10ms	No voltage reapplied	
		375		t = 8.3ms		
		300		t = 10ms	100% V_{RRM} reapplied	
		315		t = 8.3ms		Sinusoidal half wave, Initial T_J = T_J max.
I^2t	Maximum I^2t for fusing	637	A^2s	t = 10ms	No voltage reapplied	
		580		t = 8.3ms		
		450		t = 10ms	100% V_{RRM} reapplied	
		410		t = 8.3ms		
$I^2\sqrt{t}$	Maximum $I^2\sqrt{t}$ for fusing	6365	$A^2\sqrt{s}$	t = 0.1 to 10ms, no voltage reapplied. I^2t for time $t_x = I^2\sqrt{t} \cdot \sqrt{t_x}$		
$V_{T(TO)}$	Max. value of threshold voltage	0.82	V	T_J = 125°C		
r_{t1}	Max. level value of on-state slope resistance	12	mΩ	T_J = 125°C, Av. power = $V_{T(TO)} * I_{T(AV)} + r_t + (I_{T(RMS)})^2$		
V_{TM} V_{FM}	Max. peak on-state or forward voltage drop	1.35	V	T_J = 25°C, $I_{TM} = \pi \times I_{T(AV)}$		
di/dt	Maximum non repetitive rate of rise of turned on current	200	A/µs	T_J = 125°C from 0.67 V_{DRM}; $I_{TM} = \pi \times I_{T(AV)}$, I_g = 500mA, tr < 0.5µs, tp > 6µs		
I_H	Maximum holding current	130	mA	T_J = 25°C anode supply = 6V, resistive load, gate open		
I_L	Maximum latching current	250	mA	T_J = 25°C anode supply = 6V, resistive load		

Blocking

	Parameter	P100	Units	Conditions
dv/dt	Maximum critical rate of rise of off-state voltage	200	V/µs	T_J = 125°C, exponential to 0.67 V_{DRM} gate open
I_{RRM} I_{DRM}	Max. peak reverse and off-state leakage current at V_{RRM}, V_{DRM}	10	mA	T_J = 125°C, gate open circuit
I_{RRM}	Max peak reverse leakage current	100	µA	T_J = 25°C
V_{INS}	RMS isolation voltage	2500	V	50Hz, circuit to base, all terminal shorted, T_J = 25°C, t = 1s

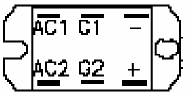
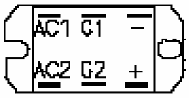
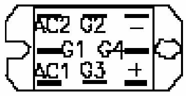
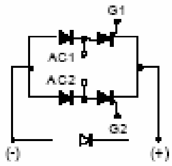
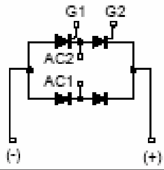
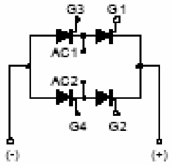
Triggering

	Parameter	P100	Units	Conditions	
P_{GM}	Maximum peak gate power	8	W		
$P_{G(AV)}$	Maximum average gate power	2	W		
I_{GM}	Maximum peak gate current	2	A		
- V_{GM}	Maximum peak negative gate voltage	10	V		
V_{GT}	Maximum gate voltage required to trigger	3	V	T_J = - 40°C	Anode Supply = 6V resistive load
		2		T_J = 25°C	
		1		T_J = 125°C	
I_{GD}	Maximum gate current required to trigger	90	mA	T_J = - 40°C	Anode Supply = 6V resistive load
		60		T_J = 25°C	
		35		T_J = 125°C	
V_{GD}	Maximum gate voltage that will not trigger	0.2	V	T_J = 125°C, rated V_{DRM} applied	
I_{GD}	Maximum gate current that will not trigger	2	mA	T_J = 125°C, rated V_{DRM} applied	

Thermal and Mechanical Specification

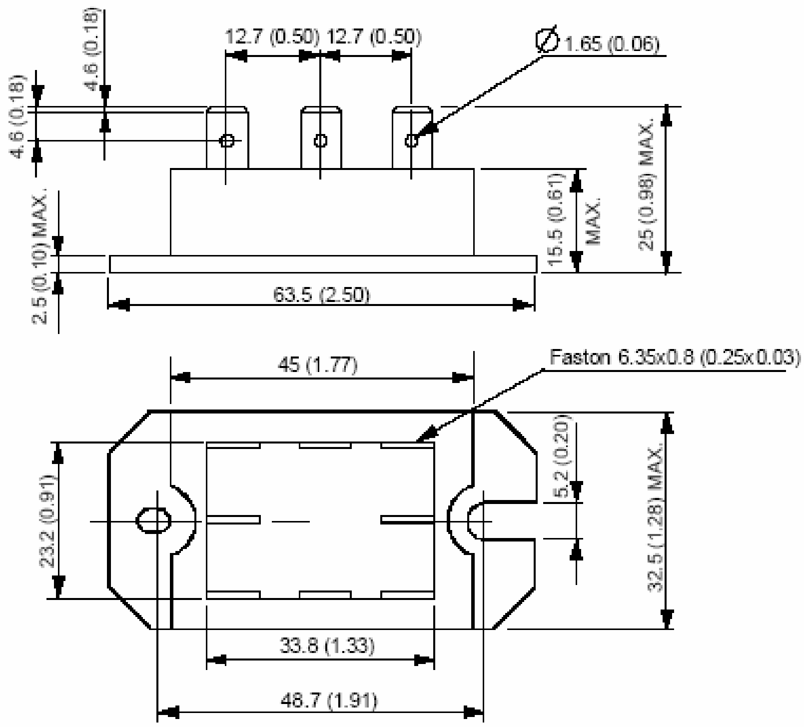
	Parameter	P100	Units	Conditions
T_J	Max. operating temperature range	-40 to 125	°C	
T_{stg}	Max. storage temperature range	-40 to 125	°C	
R_{thJC}	Max. thermal resistance, junction to case	2.24	K/W	DC operation per junction
R_{thCS}	Max. thermal resistance, case to heatsink	0.10	K/W	Mounting surface, smooth and greased
T	Mounting torque, base to heatsink	4	Nm	A mounting compound is recommended and the torque should be checked after a period of 3 hours to allow for the spread of the compound
wt	Approximate weight	58 (2.0)	g (oz)	

Circuit Type and Coding *

	Circuit"0"	Circuit"2"	Circuit"3"
Terminal Positions			
Schematic diagram diagram			
	Single Phase Hybrid Bridge Common Cathode	Single Phase Hybrid Bridge Doubler	Single Phase All SCR Bridge
Basic series	P10.	P12.	P13.
With voltage suppression	P10.K	P12.K	P13.K
With free-wheeling diode	P10.W	-	-
With both voltage suppression and free-wheeling diode	P10.KW	-	-

* To complete code refer to voltage ratings table, i.e.: for 600V P10.W complete code is P102W

Outline Table



All dimensions in millimeters (inches)

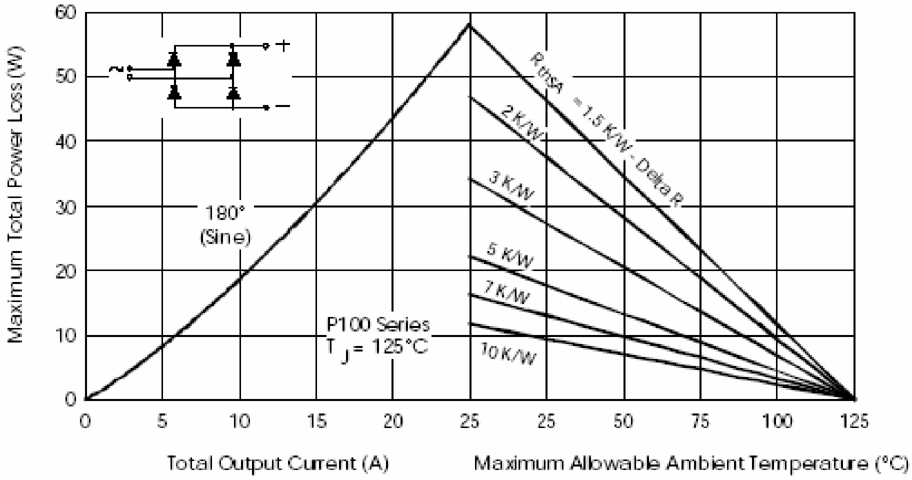


Fig. 1 - Current Ratings Nomogram (1 Module Per Heatsink)

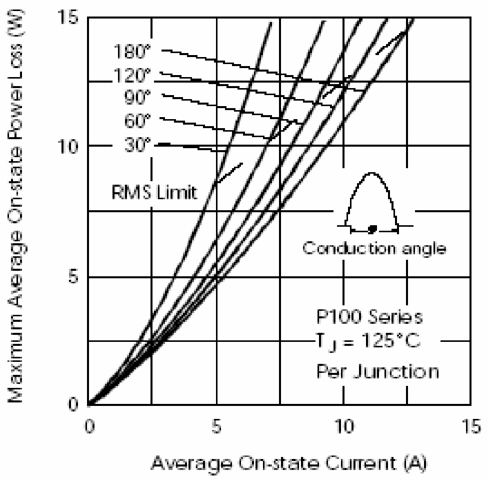


Fig. 2 - On-state Power Loss Characteristics

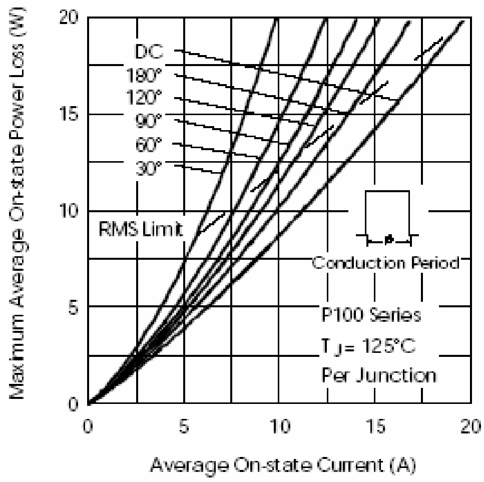


Fig. 3 - On-state Power Loss Characteristics

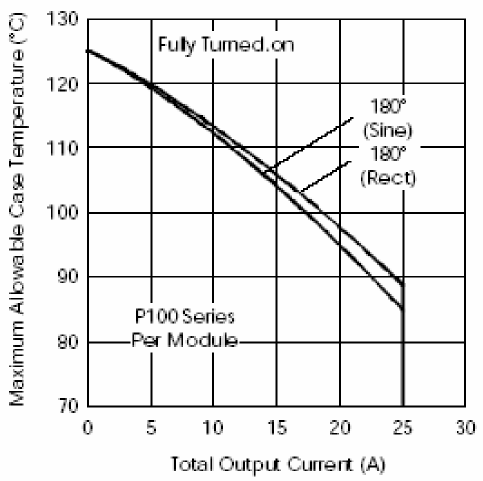


Fig. 4 - Current Ratings Characteristics

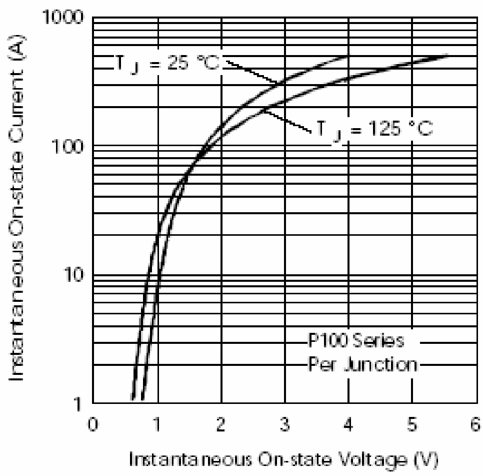


Fig. 5 - On-state Voltage Drop Characteristics

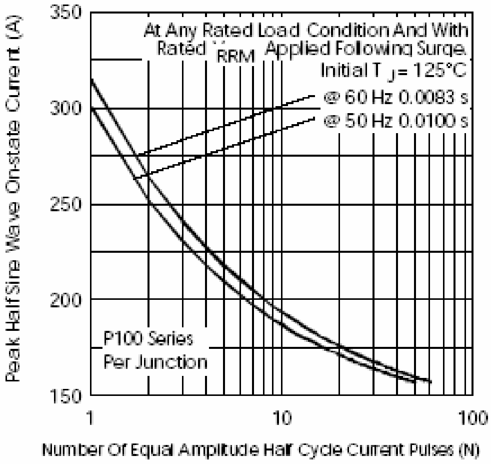


Fig. 6 - Maximum Non-Repetitive Surge Current

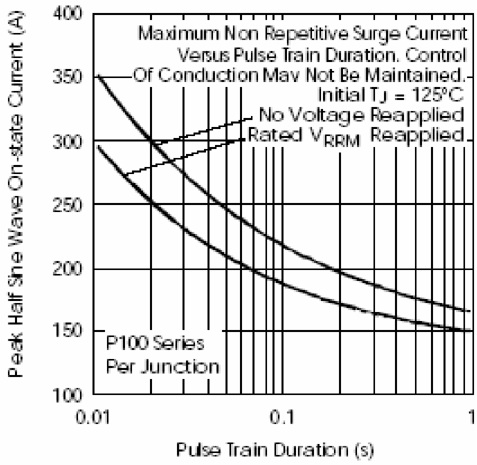


Fig. 7 - Maximum Non-Repetitive Surge Current

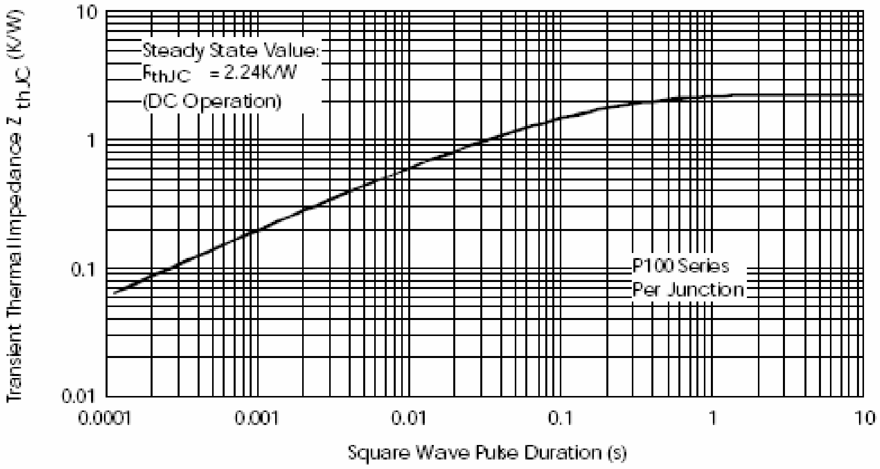


Fig. 8 - Thermal Impedance Z_{thJC} Characteristics

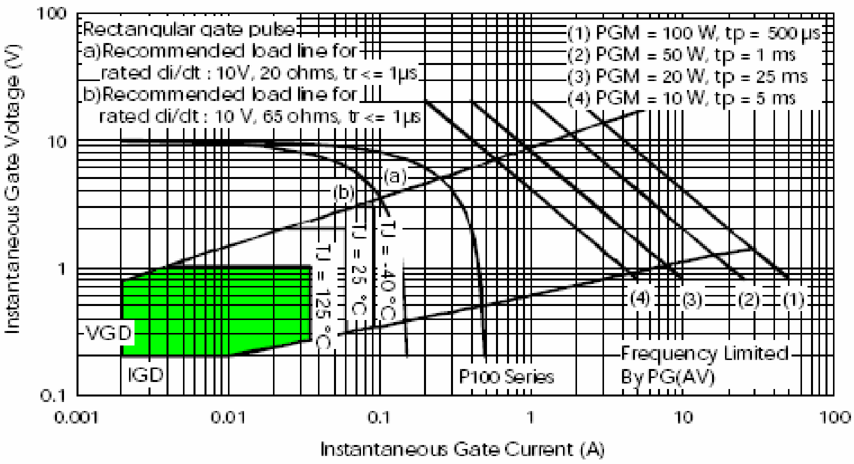


Fig. 9 - Gate Characteristics

APPENDIX D – AFM11 DATA SHEET

UNITED AUTOMATION

UNIVERSAL PHASE ANGLE TRIGGER MODULE

AFM-11

X10221

INTRODUCTION

This single phase or phase to phase trigger module uses variable phase angle control with adjustable signal matching, integral current limit input and adjustable soft start. The pulse train output is reliable, powerful and universally applicable to resistive or inductive loads. The power transformer is remote for increased reliability and wide operational voltage capability. Adjustable current limit allows feedback control and via a few external parts, this can also give voltage or speed control of AC or DC loads. The module is fully enclosed for safety and eligibility in industrial environments.

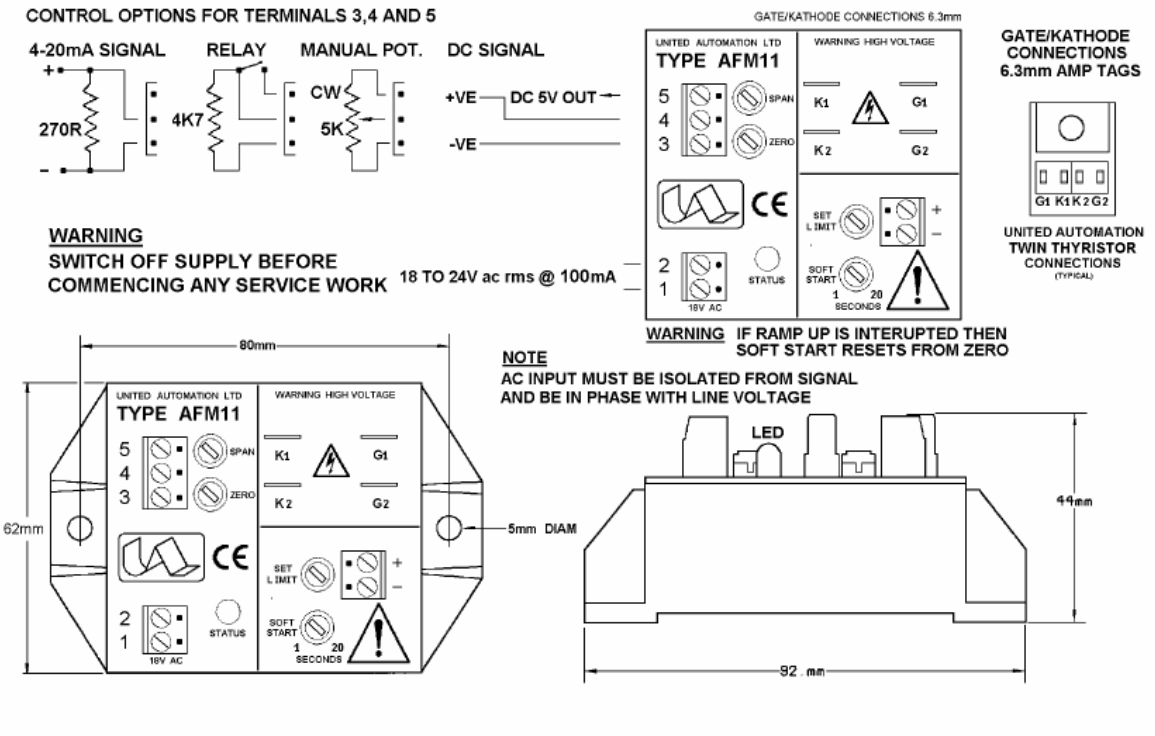
APPLICATIONS

Applicable to most AC or DC, resistive or inductive loads via thyristor, triac or hybrid diode stacks on single phase to neutral, or phase to phase supplies, within voltage limits.

FEATURES

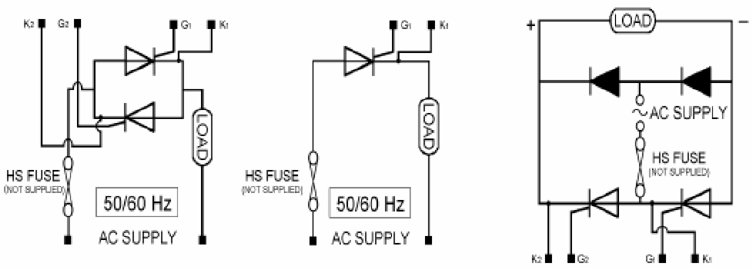
- Fires triacs or thyristors up to 480V, 50/60 Hz supplies.
- Adjustable soft start function.
- Adjustable current limit control.
- Pulse train firing via isolation transformer.
- Consumes under 2 watts.
- Status indication

INSTALLATION



POWER CONNECTIONS

FULL WAVE THYRISTORS HALF WAVE - THYRISTOR DC CONTROLLED



SPECIFICATIONS

Signal Span minimum	0 to 2.5V dc	AC input supply (nominal)	18 to 24V rms @ 100mA
Signal Span maximum	0 to 25V dc	Auxiliary output (nominal)	5V dc @ 20mA protected
Signal Zero offset	0 to 50% of span	Thyristor line voltage	110 to 480V rms @ 50/60 Hz
Signal input resistance	5000Ω ± 20%	Manual potentiometer	2KΩ, 5KΩ or 10KΩ
Trigger pulse height	8V open circuit	Limit feedback input	0.6 - 30V dc
Trigger pulse rating	250mA in to 10Ω	Soft start	0-20 seconds
Trigger isolation voltage	2500V rms	Storage temperature	-20°C to +85°C
Trigger shorted output	Protected	Operating temperature	0°C to 75°C

FUSING

It is recommended to use semiconductor (fast acting) type fuses or circuit breakers (Semiconductor - MCB) for unit protection and an appropriate safety fuse for the units supply (F1A). On initial 'switch on' some loads may need an increased factor of safety (F of S) for unit and/or device protection. (See the SRA Datasheet for further information).

CE MARKING

This product family carries a "CE marking". These phase angle controllers need a suitable remote filter. For information see recommendation section and contact our sales desk. (See the Declaration of Conformity).

RECOMMENDATIONS

Other documents available on request, which may be appropriate for your application:-

CODE	IDENTITY	DESCRIPTION
X10229	RFI	Filtering recommendations - addressing EMC Directive
X10213	ITA	Interaction, uses for phase angle and for burst fire control.
X10255	SRA	Safety requirements - addressing the Low Voltage Directive (LVD) including:- Thermal data/cooling ; "Live" parts warning & Earth requirements; Fusing recommendations.
AP02/4	COS	UAL Conditions of sale.

NOTE It is recommended that installation and maintenance of this equipment should be done with reference to the current edition of the I.E.E. wiring regulations (BS7671) by suitably qualified/trained personnel. The regulations contain important requirements regarding safety of electrical equipment (For International Standards refer to I.E.C. directive IEC 950).

ORDER CODE

State part number: AFM11

Optional extras include: Potentiometer, Supply transformer, complete assemblies, Filter.
When ordering a filter the current of the load is required.

UNITED AUTOMATION LIMITED
1Southport Business Park
Kew
Southport, PR8 4HQ
ENGLAND
Tel: 0044 (0) 1704 – 516500 Main
Tel: 0044 (0) 1704 – 516516 Sales
Fax: 0044 (0) 1704 – 516501
Enquiry@united-automation.com

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ISO 9002 REGISTERED COMPANY UKAS QUALITY MANAGEMENT 015

APPENDIX E – EQUIPEMENT COST

Name : BAVARIN Rudolph Date : 8/08/2006
Discipline : BENG ELE

farnell
2005

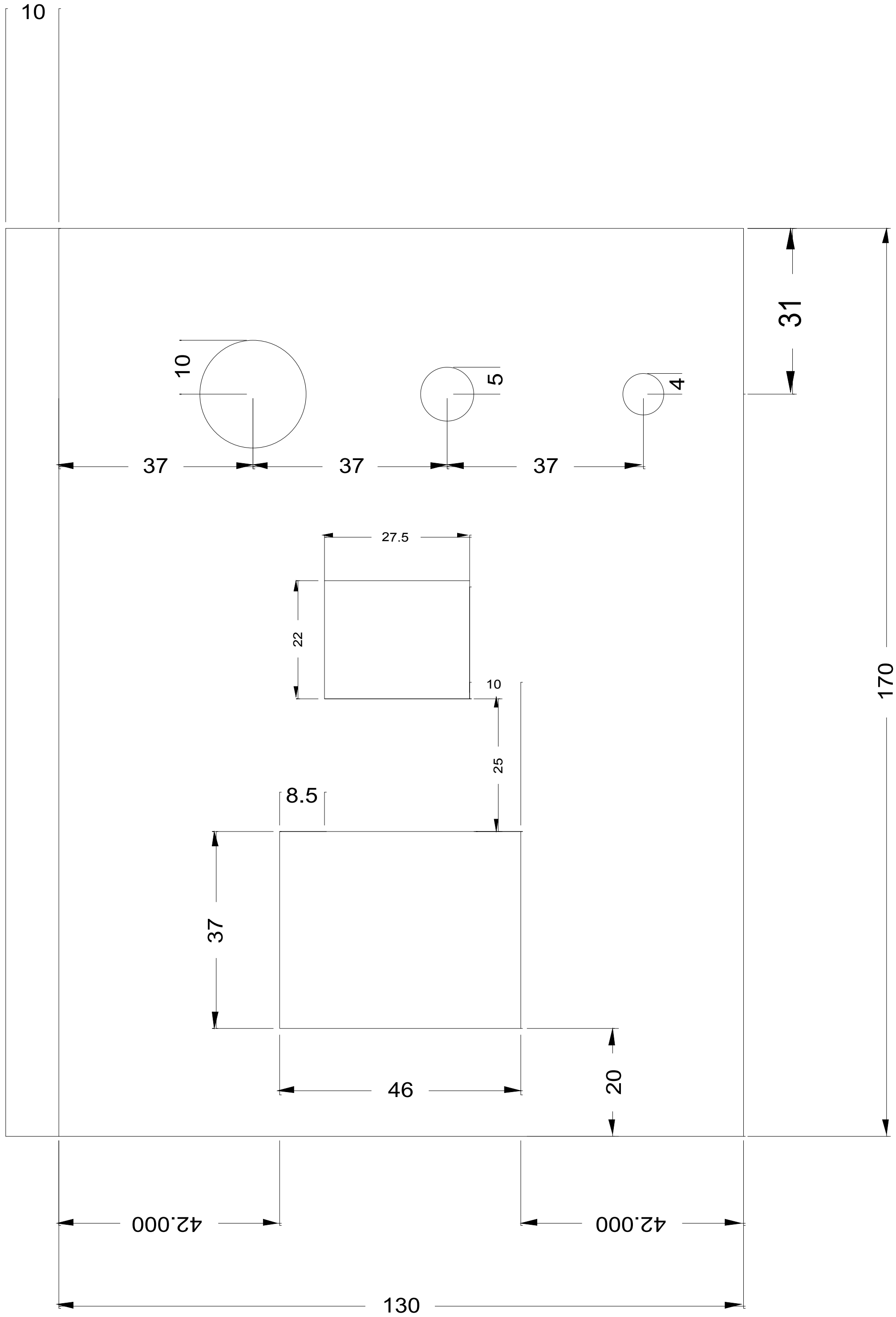
Project : 50kW Eddy current Braking

Order code	Part number	Description	Qty	price	cost	Page
178-756	AFM-11	Trigger module	1	273.7	273.68	1/837
351076	CLR11069S5K0K	potentiometer 5K	1	35.59	35.59	1/742
890-935	1/4 fine aluminium (grub screw)	potentiometer knob	1	6.01	6.01	2/303
362-530	P102W B2HKF config	thyristor diode bridge	1	121.3	121.34	1/831
696-547	12VA-12% regulation	Transformer Clamp mounting	1	19.28	19.28	2/1016
427-4527	M3MVR	Multifunction voltage relay	1	245	245	2/526
443-4470	green	SPNO Momentary	1	17.26	17.26	2/752
560-650	DPCO - 5532 series	10 A relay	1	20.12	20.12	2/593
335-4131	double surface 1.15	heat sink	1	42.29	42.29	1/863

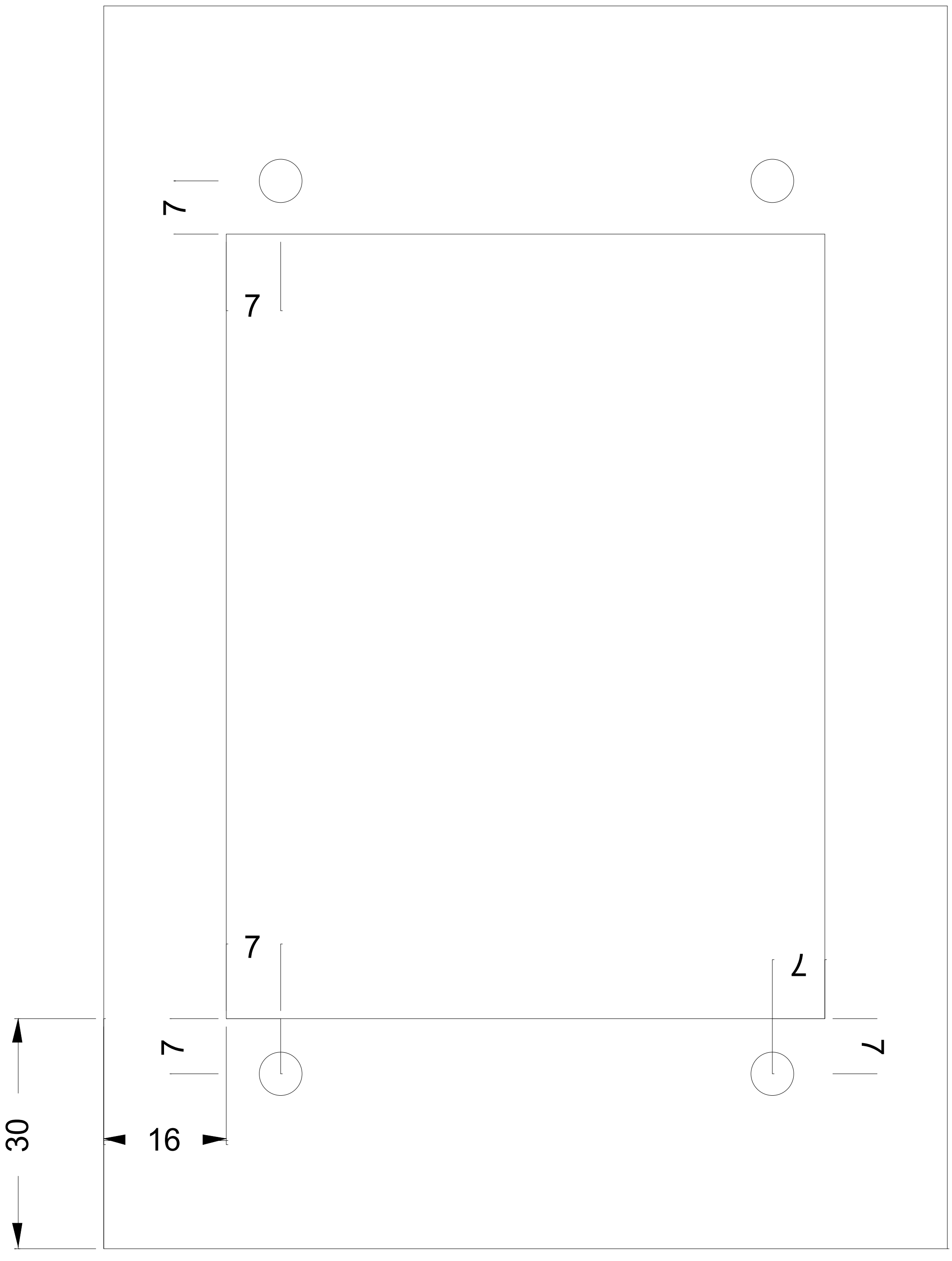
Total	780.57

APPENDIX F – CONTROL UNIT BOX DESIGN

FRONT VIEW



BACK VIEW



SIDE VIEW