ADMIRALTY
AIR MINISTRY

ELECTRICAL MANUAL, GENERAL

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Section 13. List of Chapters: *delete* " (*To be issued later*) " after the title of Chapter 4, and *write* " (A.L.30) " in the outer margin against the deletion. *Insert* this Chapter 4 to follow Chapter 3. *Record* the incorporation of this A.L. in the Amendment Record Sheet.

Chapter 4

JET PIPE TEMPERATURE CONTROL EQUIPMENT

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Introduction

1. The efficiency of an aircraft gas turbine increases as the temperature of the gases in the turbine increases and it is therefore desirable that the temperature of these gases should be as high as possible to obtain a large power output.

2. The maximum permitted temperature depends upon the material of the turbine blading as the life of these blades falls very rapidly with increasing temperature and, in fact, a comparatively small rise above the normal operating temperature can cause a dangerous reduction in blade life.

3. A compromise is therefore necessary to establish an optimum temperature where maximum power is obtained without impairment of blade life, and this can be reached by careful control of the turbine operating conditions. This control can be instituted at ground level and means are available for compensating for the effect of changes in altitude. Certain other factors remain, however, which can cause excessive turbine temperature, such as high ambient temperature and reduction in airflow due to the compressor being " bled " to provide air for cabin services, etc.

4. The best method of preventing undesirable temperatures from occurring is to measure the temperature and, after a predetermined limit has been reached, to reduce progressively the fuel flow to the power unit. This chapter gives, in general terms, information on equipment that fulfils this requirement. Details of any specific component of jet pipe temperature control equipment will be included in A.P.4343E, Vol. 1.

Principles

5. Ideally, the temperature measured should be that of the actual turbine blading, but practical difficulties prevent such measurement. The method adopted, therefore, is the usual one of temperature measurement by thermocouples installed in the jet pipe immediately after the turbine.

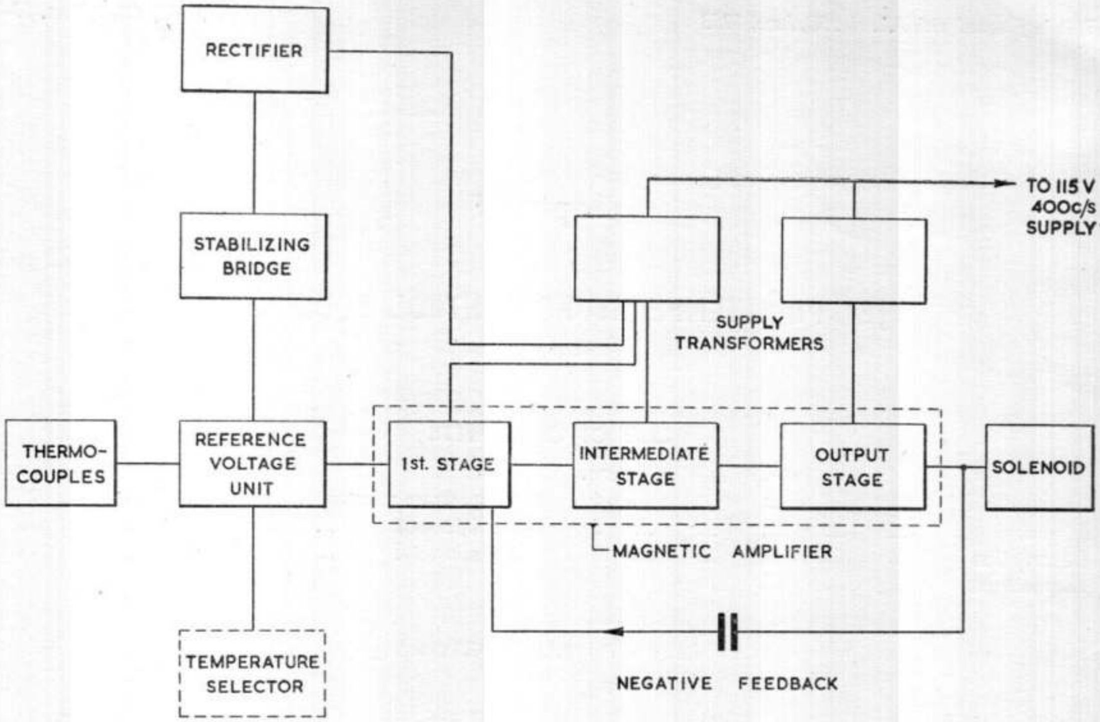

Fig. 1. Block diagram, typical jet pipe temperature control system

6. The voltage generated by the thermocouples, due to the difference in temperatures between the "hot" and "cold" junctions, is fed into a "reference voltage" unit. This unit supplies a stabilized voltage equal to the e.m.f. given by a thermocouple at the desired limiting temperature. The stabilized reference voltage must be adjustable by some external device in order to suit different installations and requirements, and must be compensated for the changes in thermocouple e.m.f. with changes in ambient ("cold" junction) temperature.

7. This compensation is arranged internally, whilst the reference voltage is adjusted by a temperature selector. The selector provides a means whereby the temperature at which the control system starts to operate may be pre-set, as in "temperature limiting" control, or may be adjusted according to the throttle setting as in "range" control.

8. The reference voltage unit, then, provides a pre-determined e.m.f. value and also receives the varying e.m.f. output from the thermocouples. These two values are compared and if they are equal, the reference voltage is balanced and the output from the reference voltage unit is zero. If there is a difference between the two values, a signal is fed to a magnetic amplifier which is arranged to give an output only when the thermocouple e.m.f. is greater than the reference voltage. Such output is led to a solenoid-operated valve which, by means of a hydraulic servo, controls the quantity of fuel fed to the turbine burners.

9. Feedback from the output stage of the amplifier is taken to the input of the intermediate stage in order to increase the time lag in the amplifier. This smooths out any "hunting" of the solenoid which would give rise to continuous variations in fuel supply leading to undesirable fluctuations of turbine thrust.

10. The resultant effects of a typical system operating on the principles outlined in the preceding paragraphs are as follows, whilst a block diagram of such a system is given in fig. 1.

11. The thermocouple temperature-amplifier output current characteristics are as shown in A, fig. 2. As the jet pipe temperature increases, so does the temperature of the thermocouple. In the event of this temperature reaching the pre-selected value, the amplifier output commences to increase,

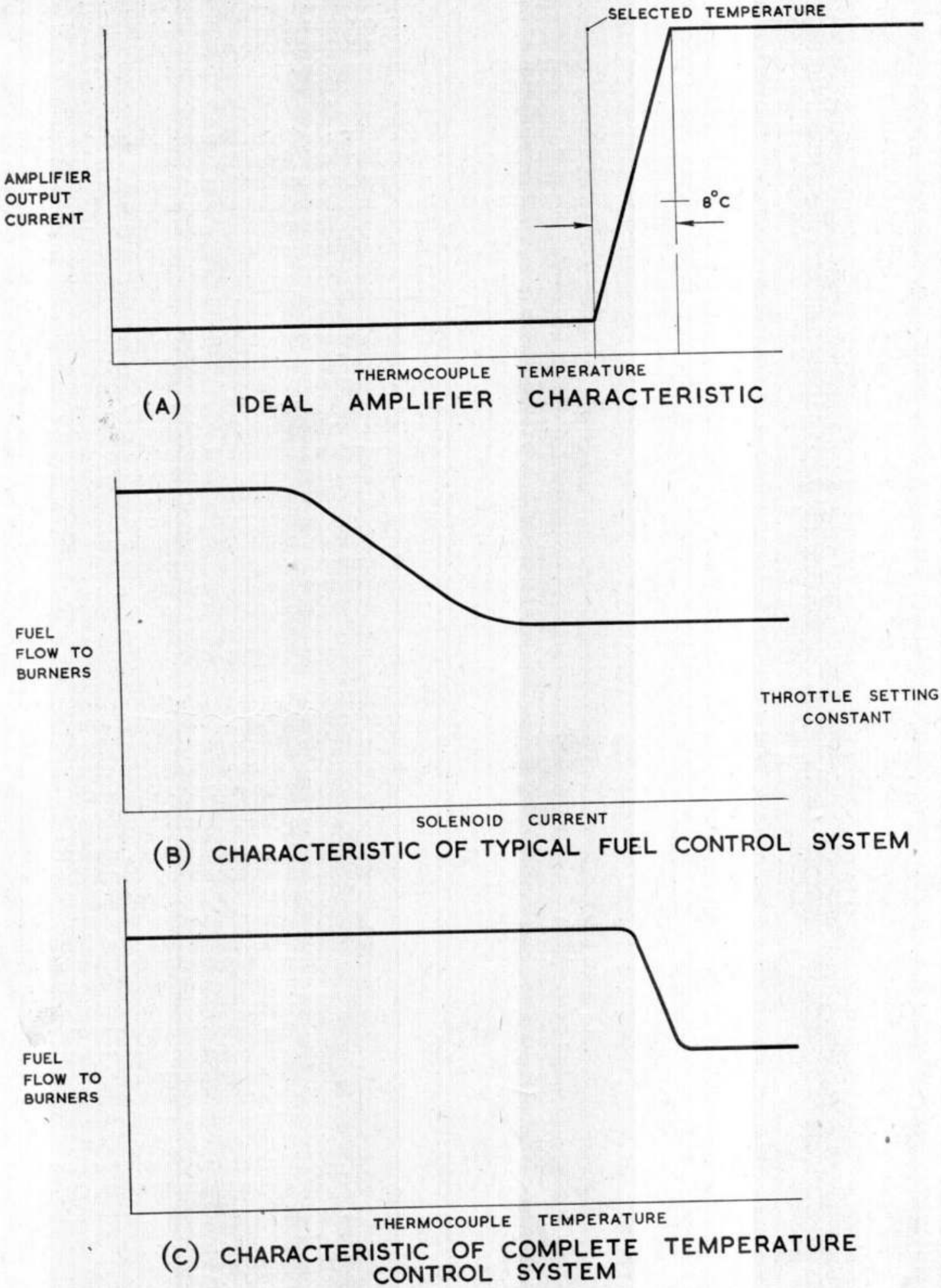

Fig. 2. Operating characteristics of a typical jet pipe temperature control system

reaching a constant maximum value for a further temperature increase of approximately 8 deg. C.

12. Solenoid current-fuel flow depends on the type of fuel system used, but is usually of the form shown in B, fig. 2. As the solenoid current increases, and with a constant throttle setting, the fuel flow to the burners is decreased. The combination of these two characteristics gives a thermocouple temperature-fuel flow characteristic as shown in C, fig. 2.

DESCRIPTION

13. The components of a typical jet pipe temperature control system include the thermocouples, a temperature selector, a solenoid valve, and an amplifier unit which incorporates a magnetic amplifier, a full-wave rectifier, a stabilizing bridge, and a reference voltage unit.

Thermocouples

14. The thermocouples, which are usually of the chromel-alumel type, may vary in number between installations and are mounted radially in the jet pipe and connected in parallel. This method of connection ensures that if one thermocouple fails the system continues to function, merely taking the average of, say, three temperatures instead of the average of four.

15. Each thermocouple is normally connected to a terminal block near the jet pipe, connection between this terminal block and the amplifier being made by a suitable extension lead. The total resistance of the thermocouple circuit, including the extension lead, must not exceed 20 ohms. A typical thermocouple and extension lead is shown in fig. 3.

16. Since a thermocouple depends for its operation on the difference in temperature existing between the "hot" and "cold" junctions, it follows that changes in ambient temperature affecting the "cold" junction, which in this application is the terminal block on the amplifier unit body, will also affect the thermocouple output.

17. Compensation for this effect is included in the reference voltage network housed within the amplifier unit, but it is pertinent to discuss it here. It has already been stated that the values of the thermocouple e.m.f. and the reference voltage e.m.f. are compared and if they are equal, the input to the magnetic amplifier is zero. Consider a control system operating under these conditions which is then subjected to a decreased ambient temperature. The temperature of the "cold" junction falls, the difference in temperatures between the "hot" and "cold" junction increases, and, therefore, the e.m.f. generated by the thermocouple increases.

18. Thermocouple e.m.f. would now exceed reference voltage e.m.f. and a positive signal would be fed to the magnetic amplifier which would cause the solenoid valve to commence restriction of the fuel supply.

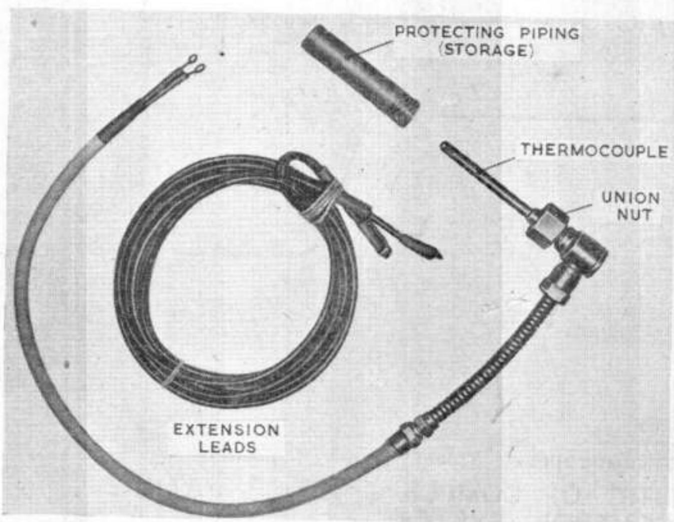

Fig. 3. Typical thermocouple and extension leads

19. To counteract this, the reference voltage network resistors, normally formed of a material with a negligible temperature coefficient such as Eureka, include a "cold" junction compensator coil wound of some material, usually copper, the property of which is such that a decrease in temperature causes a decrease in resistance. This coil is normally secured to the back of the thermocouple terminal block on the amplifier unit, thus ensuring that it is subjected to the same changes in ambient temperature as the "cold" junction.

20. In the example under discussion, therefore, the resistance of the "cold" junction compensator coil will decrease, which will consequently decrease the overall resistance of the reference voltage unit. The e.m.f. available for comparison with the increased thermocouple e.m.f. will thus have increased, thereby restoring the balance between the two values.

Temperature selector

21. The temperature selector used with this equipment may vary between different types of installations and engines as the design of this unit for the particular requirements of a specific type of engine rests with the engine manufacturer. Its function, however, remains the same.

22. Since the thermocouple e.m.f. is compared with the reference voltage e.m.f., and the difference is then amplified to give a power output sufficient to operate the fuel control solenoid, it will be appreciated that a variation in the reference voltage will result in a change in the turbine control temperature. It is the purpose of the temperature selector to determine this reference voltage.

23. One of two systems may be adopted in the setting of the reference voltage.

(1) It may be pre-determined and set at ground level to ensure that the jet pipe temperature does not exceed a certain value, or

(2) It may be continuously variable with the throttle to ensure that the jet pipe temperature does not exceed the optimum value for that particular throttle setting.

24. In system (1), "temperature limiting control," the temperature selector normally consists of a resistor network having two fixed resistors (*fig.* 4).

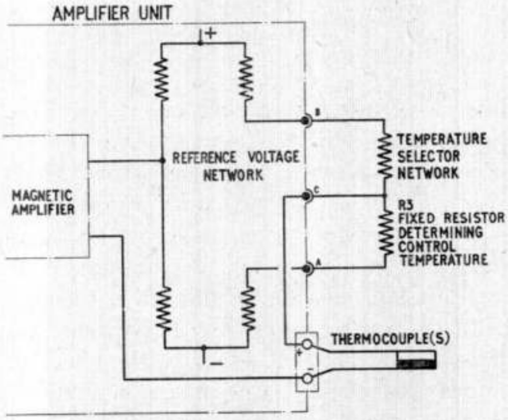

Fig. 4. Schematic circuit—typical temperature selector ("temperature limiting control")

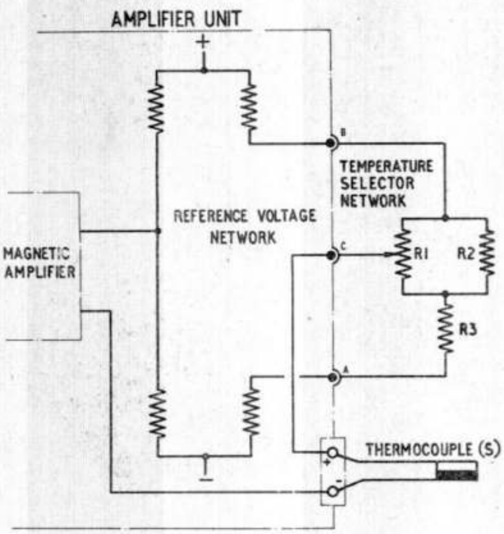

Fig. 5. Schematic circuit—typical temperature selector ("range control")

25. In system (2), "range control," the network would normally be as shown in fig. 5 where the variable resistor R1 is mechanically coupled with the throttle. This resistor is usually a standard stud switch, the controlling function of which is made to conform to the requirements of an individual engine by the trimmer resistors R2 and R3. By using suitable values for these resistors, the temperature selector can alter the reference voltage over a range sufficient to cause the amplifier to control the turbine temperature at any point between 350 deg. and 800 deg. C.

Amplifier unit

26. The power available from the difference in thermocouple e.m.f. and reference voltage is very small, being of the order of 0·0002 microwatts, yet the power required to operate the fuel control solenoid is approximately 2 or 3 watts. The function of the amplifier is to amplify this small input signal to a signal which has sufficient power to operate the solenoid.

27. While the internal construction of different types of amplifier units may vary, they are externally similar and fully interchangeable. A typical unit is illustrated in fig. 6.

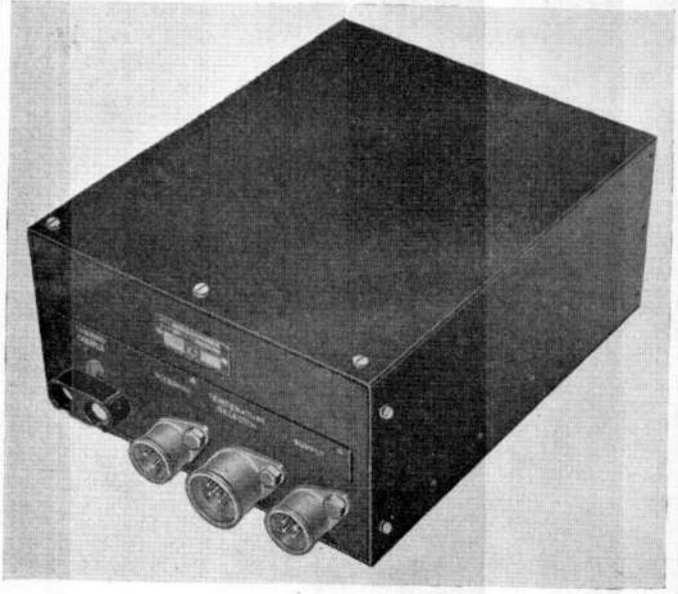

Fig. 6. External view of typical amplifier unit

28. One end of the amplifier unit carries the necessary plugs and terminal block for connection to the power supply and other components of the control equipment. A 4-pole plug (only 3 poles of which are used) facilitates connection to the aircraft supply which is 3 phase, 115-volt, 400 c/s. A 5-pole plug (only 3 poles of which are used) connects the amplifier unit to the temperature selector, whilst a 2-pole plug connects to the solenoid-operated valve. A terminal block receives the extension lead from the thermocouples.

29. The amplifier unit is totally enclosed by a metal cover, to the bottom face of which are fitted four mounting bushes to facilitate securing of the unit to the airframe structure.

30. Internal views (*fig.* 7) of a typical amplifier unit show the various components contained within the cover. In this particular type, the 115-volt, 400 c/s supply is fed to two transformers. A secondary winding of one of these transformers is connected to a full-wave metal rectifier which supplies a direct current to the stabilizing bridge, while further windings feed the first and intermediate stages of the magnetic amplifier. The output stage of the amplifier is fed from the secondary windings of the remaining transformer. The stabilizing bridge is an arrangement of resistors which includes a "Metrosil" component as a non-linear element and feeds a stabilized voltage to the reference voltage unit which is connected to the temperature selector and thermocouples. The network includes the "cold" junction compensator coil which corrects for changes in the thermocouple e.m.f. when the ambient ("cold" junction) temperature varies (*para.* 16 *to* 20).

31. The difference between the thermocouple and reference voltage is fed to the first stage of the magnetic amplifier. The amplified output signal is then fed via an intermediate stage to the output stage. The first and intermediate stages are balanced and respond to signals of either polarity of input whilst the output stage gives output for only one direction of input signal. This ensures that output current is produced only when the jet pipe temperature is in excess of the selected value.

32. A feedback unit is connected from the output stage to the input of the intermediate stage and is used to increase the time lag in the amplifier to obtain stability of the control system.

33. The output from the final stage of the amplifier is fed, after rectification, to the solenoid valve controlling the fuel flow. Fig. 8 shows an ideal thermocouple temperature-solenoid current characteristic for the temperature control amplifier. Region A indicates the standing output current to the solenoid; B the controlling range, and C the saturation current. It will be seen that the standing output current of 50mA or less is increased to about 450mA over the controlling range of 8 deg. C.

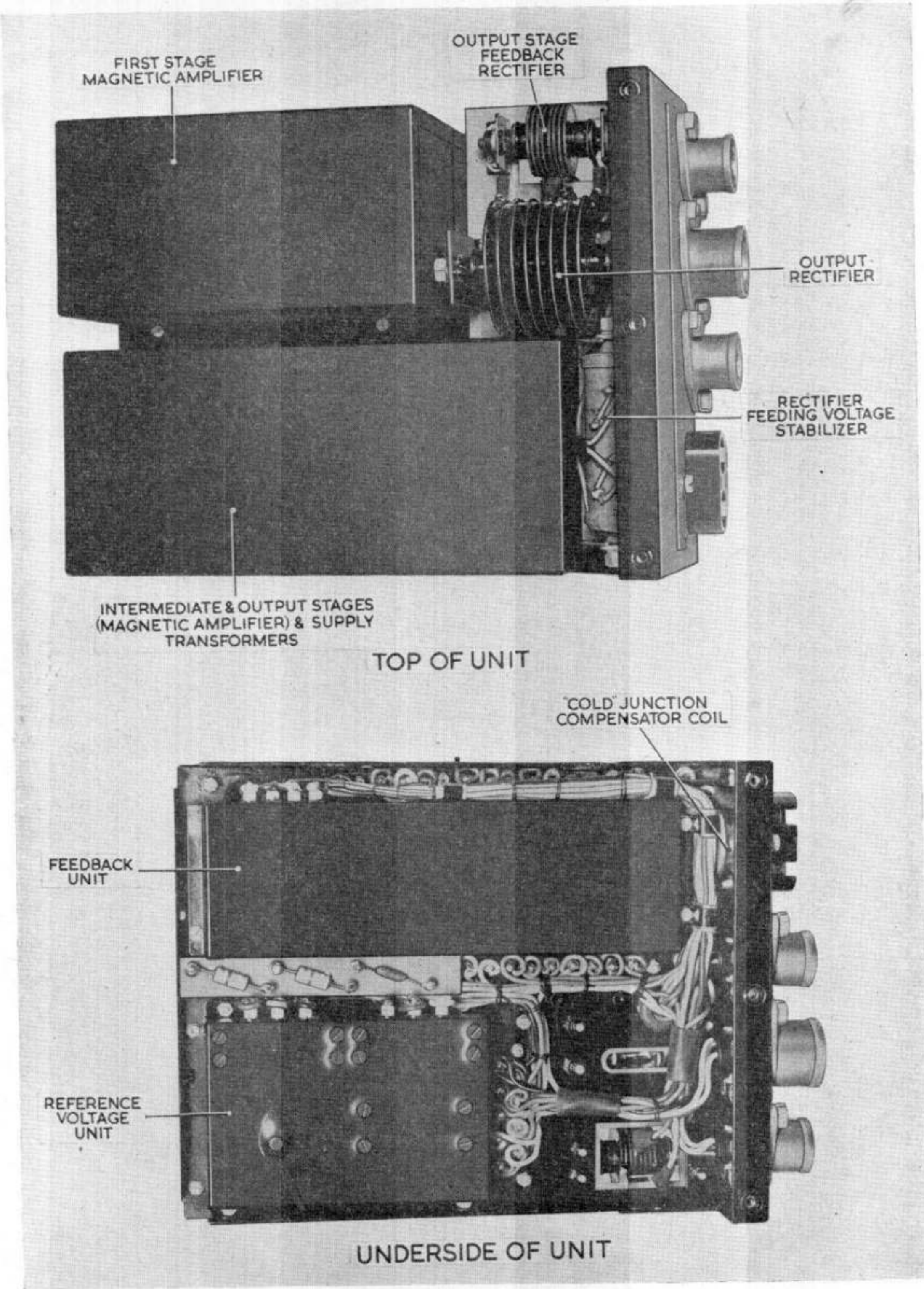

Fig. 7. Internal views of typical amplifier unit

Solenoid valve

34. The solenoid valve is merely a device which converts the output signal from the amplifier into a mechanical movement which, by means of a hydraulic servo, restricts the fuel flow. The construction of this component may vary between different types of engine and it may also be an integral part of a fuel flow control unit. For these reasons, it is not possible to give a description of any particular solenoid valve in this chapter. Such details will be included in A.P.4343E, Vol. 1 and/or in the relevant engine Air Publication.

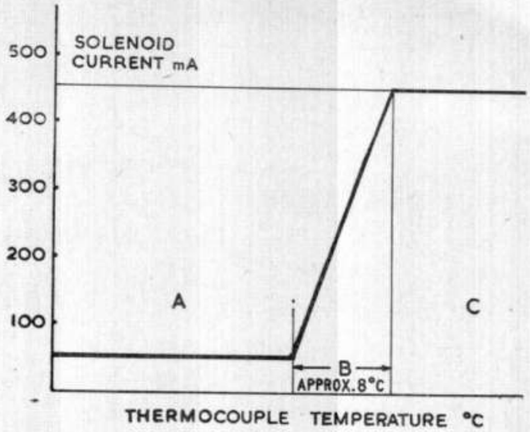

Fig. 8. Ideal thermocouple temperature-solenoid current characteristic

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DANGER
CANOPY
DANGER
EJECTION SEAT
ENTRANCE OTHER SIDE