MICROPROCESSOR BASED CONTROL SYSTEM FOR CLOSE LAYING OF COILS IN THE WIRE ROD MILL COILER

A DISSERTATION

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MASTER OF ENGINEERING
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By

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C_E_R_T_I_F_I_C_A_T_E.

Certified that the dissertation entitled 'Microprocessor Based Control System for close laying of coils in the wire rod mill coiler', which is being submitted by Mr. Girijesh in partial fulfilment for the award of MASTER OF ENGINEERING degree in MEASUREMENT AND INSTRUMENTATION of the University of Roorkee, is a record of students own work carried out by him under our supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other degree or diploma.

This is to further certify that he has worked for a period of one year and six months from March, 1982 to August, 1983 as part time candidate for preparing this dissertation.

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A C K N O W L E D G E M E N T

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S Y N O P S I S

Coiler of wire rod mill is an important portion of overall wire rod manufacturing process. It is necessary to use coiler for coiling of finished wire rods because of its thinner cross-section, longer and nonstranded lengths. Optimum utilization of coiling space is of utmost importance in this process. In order to improve upon commercial acceptability it is also necessary to avoid end projections. In general present Wire Rod Mills do not fulfil these requirements. This dissertation is therefore aimed at suggesting an experimentally verified method to achieve compact coils.

A Wire Rod Mills, which is in operation at finishing zone of Bhilai Steel Plant, has been considered for arriving at suggestions for possible modifications. To start with operation of the mill has been critically studied. It was found out that in existing process

(i) Coiling operation do not give compact coils, and

(ii) the end projections of coils presents handling and quality control problems.

In order to overcome above mentioned drawbacks of present system, a new microprocessor based coiler motor speed controller has been devised and experimented with. In order to introduce safety and protection against possible malfunction of scheme, interlocking between different drives

has been retained in the suggested system also for experimentation.

It is known that close laying of coil can be achieved by proper regulation of coiler motor speed. In the suggested microprocessor scheme a base signal is generated out of last stand (i.e. 23rd) tachogenerator. The microprocessor is programmed to generate a catenary waveform in segment form which is superimposed at base signal. Firing angle of thyristor is thus decided by microprocessor output. This firing angle controlled thyristor bridge feeds coiler motor and hence decidesits speed. A signal proportional to speed is fed back to thyristor speed regulator to form a negative feed back speed regulator. With such operation speed variation of coiler motor is also of catenary shape. This enables close laying of coils.

In order to avoid end projections back end interrupts programme has been developed. It is possible to avoid backend projections through such a scheme.

Experimental test was conducted on new system and results were found to be reasonably successful with respect to the aims. Test results are given in text.

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CHAPTER - 1

INTRODUCTION

1.1 NECESSITY OF COILER IN WIRE ROD MILL (WRM)

Finished wire rod is industrially brought out in the coil form because of its thinner cross section and longer lengths. This is not the case with beams, channels, rails etc. which are manufactured in the form of cut-pieces of definite length.

Modern wire Rod Mills demand high speed of coiling operation in order to achieve higher productivity. In order to obtain high productivity, billets are rolled in number of strands simultaneously. In some mills direction of rolling is also changed, mainly to accommodate the mill in lesser length, which obviously slows down the process of rolling. Higher speed of mill operation demands sufficient co-ordination of equipments in the process, right from the first stage (charging of billets from billet yard) to last stage (piling of coils in storage yard). In such high speed mill process, the coiling operation must keep pace with fast rolling.

The coiling operation of wire rod helps to maintain quality of end products and makes its handling easy. It is convenient to kick off coils on a conveyor for transportation, to pile it in storage yard and to deliver it to prospective users. It is, therefore, very important to handle coiling operation so as to have close laying of coils in any wire rod mill. In any wire Rod Mill, this coiling operation is done by a coiler. Often the superiority of wire Rod Mill is governed by coiler system. It is in this context that coiler operation has been considered in this **dissertation.**

1.2 PRINCIPLE INVOLVED IN COILING OPERATION

Refer to Fig. 1.1

Metal rod leaving last finishing stand falls down from top through a pipe after which it passes through a hallow shaft on a rotating cone and falls in coils around fingers. The cone is rotated by an electric motor working in synchronisation with the main drive of the finishing stand.

The speed of the cone decides the diameter of the turn when metal falls over it at a particular delivery speed. The speed of the finishing stand is taken as the velocity of the metal.

Constancy of material flow dictates that the coiler speed 'ω' be related to the rolling speed 'V' as follows :

$$\omega r = V$$

The coil turn diameter is therefore

$$r = \frac{V}{\omega}$$

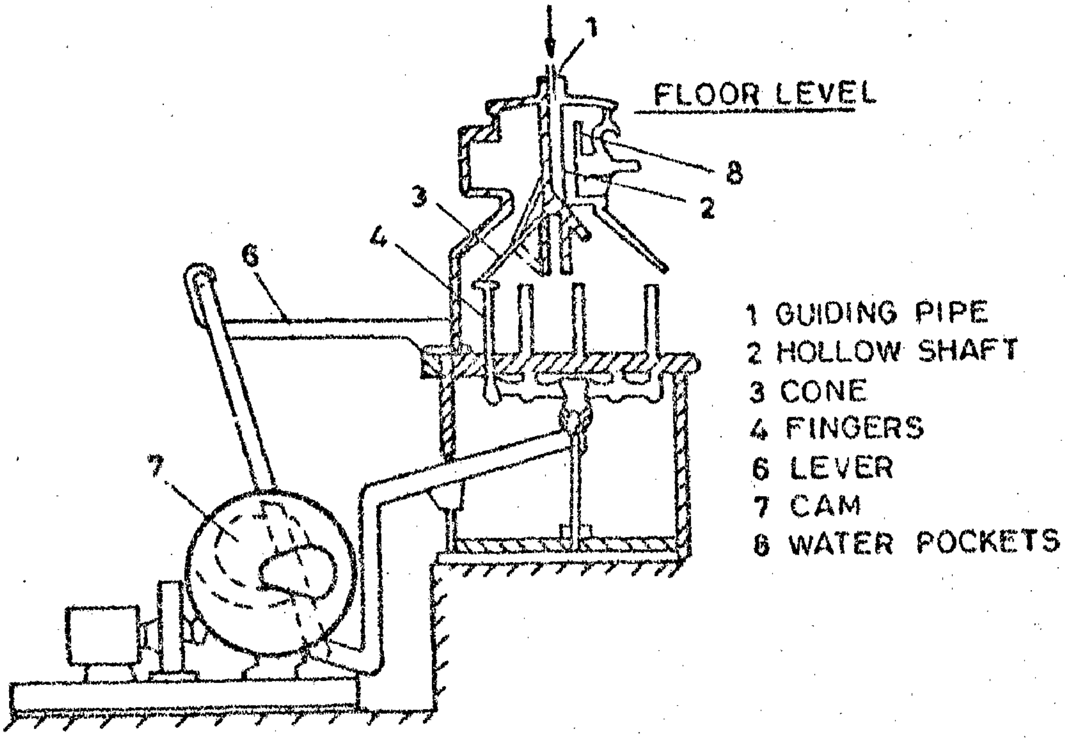

FIG.1.1. SHOWING MAIN PARTS OF COILER
(EDENBORNTYPE)

So to get a particular turn diameter the cone should be run at a definite speed to maintain above ratio.

1.3 GENERAL REQUIREMENTS TO BE SATISFIED WHILE COILING

At lower temperatures, steel becomes excessively work-hardened with simultaneous fall in plasticity, which accounts for the formation of cracks and tearing. Due to above constraint rolling is done as fast as possible, not letting the bar cool. Too much fall in temperature deteriorates the condition of bite. Overall fall in temperature in a continuous wire rod mill during rolling is of order of 150 - 160°C. The difference in temperature of back and front ends is almost nil because of the fact that the time each portion of the bar is in the mill is constant since the moment front end of the wire rod enters the coiler, the back end of the billet is still in the furnace and has suffered practically no temperature fall. Efforts are usually made to end the rolling at about 900°C because below this temperature proper rolling and coiling of metal is difficult. [7]

Synchronisation of speeds of coilers and finishing stand rolls has a large bearing on the quality of the products. With incorrect speed relation between the two, either the bar breaks apart or gets thrown out of the guiding pipes due to which a part of the finish product is wasted. [7]

Effort should be made to achieve finished coils as compact and free from end projections as possible. The loose coils pile high and reduces the utilization of storage area. The coils having lengthy front end and back end projections get sometimes, entangled with kick-off device, conveyors and are inconvenient to load and unload for further transportation to the users end.

1.4 REVIEW OF DIFFERENT TYPES OF COILERS

In Wire Rod Mills, basically two types of coilers [7] are used :

1. With fixed coils
2. With rotated coils

The first type of coiler, which is known as Edenborn type (installed at Bhilai Steel Plant) has found wide application in rolling wire rods of diameter 5 - 10 mm. The coiling speed is set according to the finishing stand speed which may exceed 30 M/sec.

The coilers with rotating coils, which is known as Garret type, performs the coiling operation without twisting the wire rod (which was the draw back of the first type). Hence they have found wide application in combination mills. For a long time the coiling speed in Garret type could not be raised beyond 10 M/sec. Improvement in design, however, have now raised it to 20 - 22 M/sec.

In some combination mills in foreign countries [7] using rotating coil system, the coilers are situated below the mill floor level. These coilers have been used for coiling round and square stock having an outside coil diameter of 1250 mm and coiling speed of 20 - 22M/sec. In some steel plants, a combination of the stationary and rotating coil systems are used by replacing the cone (of Edenborn type) by the rotating drum (Garret type).

In France and USSR, a particular design of coiler has been used to get very compact coil bundles. It consists of a rotating cone (Edenborn type) under which the coiling drum (Garret type) is located so that the rotation of the coiling drum takes place in a direction opposite to that of rotating cone, the speed being strictly synchronous and changing periodically.

CHAPTER - 2

WIRE ROD MILL AT BHILAI STEEL PLANT (UNDER PRESENT STUDY

2.1 BLOCK DIAGRAM OF COILER

Wire Rod Mill consists of 8 coilers - two numbers for each strand. All of them are of same type and work on the similar type control.

Coiler consists of a rotating cone as shown in Fig.2.1 with a helical groove to deflect the wire rod into loops which fall between a set of retractable fingers. The length of the rod in the loop as it falls freely by gravity determines the loop diameter. The inner and outer fingers set the limits of the loop size. In the case under present study, the inner and outer diameters limit are 950 mm and 1400 mm respectively.

In the considered system, the drive of the coiler runs synchronously with the finishing stand drive maintaining a definite ratio of speeds. As there is no provision for close loop speed control of the coiler motor, it runs almost at constant speed and results in the formation of coil loops having almost constant diameters. Consequently, coils tend to be uneven and piles high.

Block diagram of the control system for the coiler rotation is shown in the Fig. 2.2. The finishing stand tacho-generator feeds voltage signal (proportional to the speed of the drive) to two-stage magnetic amplifier. This inturn feeds control winding of the amplidyne. Amplidyne output voltage is connected to the generator field so that generator output varies according to the speed of finishing stand drive. Generator output feeds the coiler motor. This scheme, therefore, makes coiler motor to run at speeds governed by last finishing stand drive.

2.2 WIRE ROD MILL LAYOUT (Ref. Fig. 2.3)

Wire Rod Mills are generally specified by the diameter of roll of last working stand. The WRM of Bhilai Steel Plant has 250 mm dia. of last stand roll and it has capability to roll 5.3 mm to 10 mm diameter wire rod from square billets of 80 mm x 80 mm.

Billets which are found free from any defects after inspection in the storage yard are fed on the charging of rates of the furnace by magnetic finger cranes. The billets are fed one by one from the grate to the Reheating furnace by means of a pusher at the charging end and soaked billets are ejected out by means of ejector from the other side. Soaking is done to get uniform temperature throughout the cross section and length of the billet.

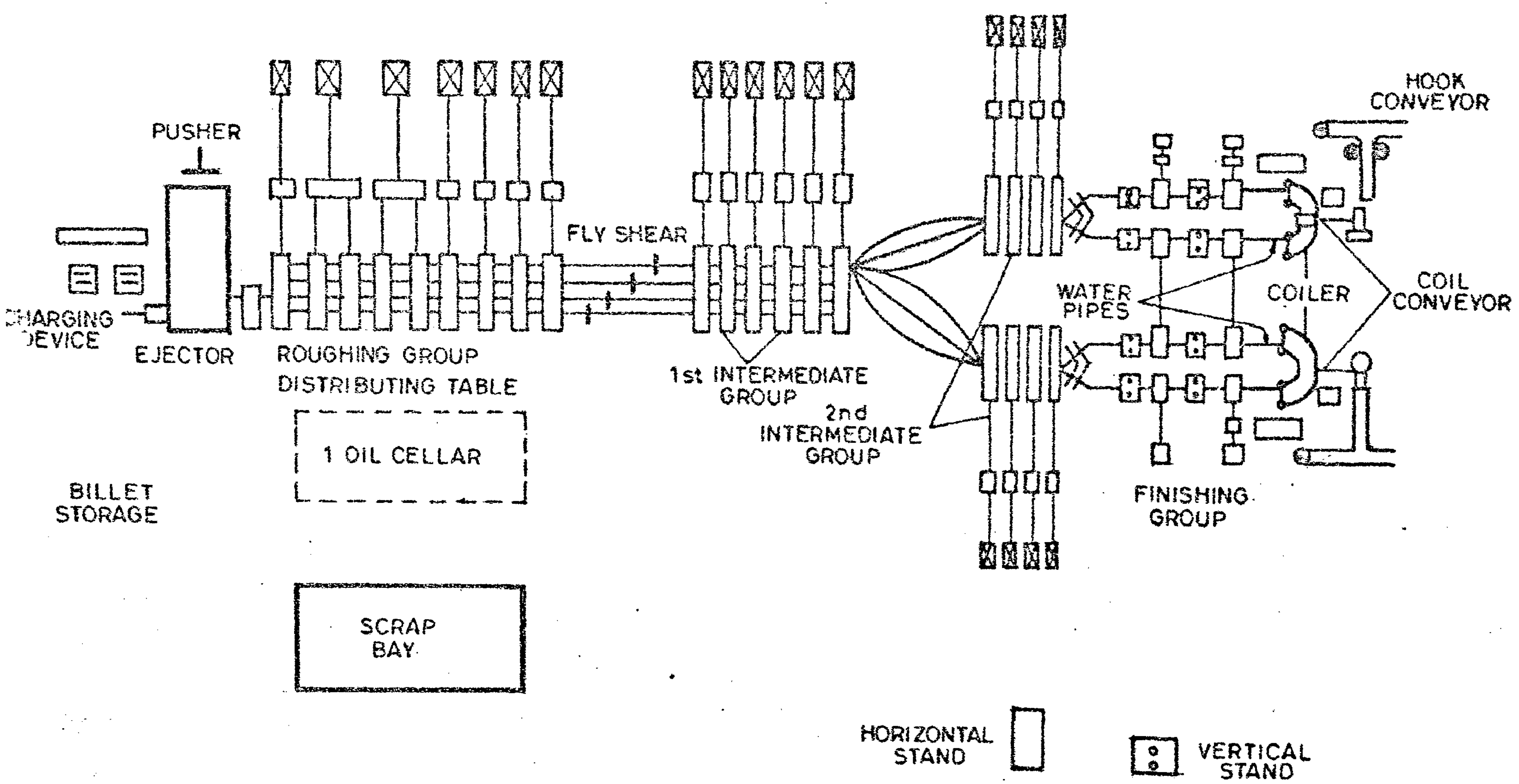

FIG.2.3. LAYOUT OF WIRE ROD MILL

The rehating furnace of size 18 x 12 meter is having 28 burners - 14 in the heating zone and 14 in the soaking zone. Coke Oven and Blast Furnace gases are fixed in a definite proportion to get the mixture of required calorific value of 1400 Kcal/m^3 and this mixture is then used as the furnace fuel. Capacity of the furnace is 120 T/hr. Gas and air are preheated in metallic and ceramic recuperators respectively.

There are 39 stands arranged in 4 groups as shown in the layout of the Mill. Fig. : 2.3

All the stands are grouped in the following manner :

No. of group	Description	Arrangement
I	Roughing group of stands	9 horizontal stands driven by motors as indicated in the lay-out diagram.
II	First Intermediate group of stands	6 horizontal stands driven by individual motors.
III	Two Second Intermediate group of Stands	Each of 4 horizontal Stands.
IV	Four Finishing group of Stands	Each consisting of 4 stands - 2 vertical and 2 horizontal driven by individual motors.

Vertical loopers are provided in between the Ist and II Intermediate group of stands and between IInd Intermediate group and Finishing group of stands.

Automatic Regulation of loop size between consecutive stands improves the quality of the finished product, reduce time due to mill setting for different grades and size of the wire-rods and consequently increases the mill productivity. The magnitude of the loop depends upon speeds in two consecutive stands, distance between the stands, coefficient of elongation and forward slips of the stands.

Such looping system simplifies mill setting since without pull the cross section of the bar does not vary much along its length.

Rolling is done in four strands in the roughing and Ist intermediate group and in two strands in the IInd intermediate group and in single strand in the finishing group of stands.

Flying shears are provided for each individual strand between the roughing group and Ist intermediate group to cut the front ends of the bars and also to cut the bar when cobble occurs in other groups. Also pneumatic snap action shears are provided before the IInd intermediate group and before finishing groups to reduce the accumulation of cobbles in the group of working stands.

Dimensions of various stands are :

Stand No.	Roll dia x roll length (mm)
1 to 7	450 x 1000
8 and 9	350 x 1000
10 to 15	300 x 800
16 to 23	300 x 600
24 to 39	250 x 400

Max. speed at the finishing stand while rolling 6 mm wire rod is 30 m/sec.

After rolling in the finishing group the metal goes to 8 mechanical coilers where it is coiled and transferred to two plate conveyors by 'KICKOFF' device. From the plate conveyors the coils are placed on two hook conveyors by a special device called 'On Loaders'.

On the hook conveyors the coils are processed, trailing ends are trimmed, coils are shaped, bound, and tightened properly.

The coils are inspected and the indentification tags and colour code are given. These finished coils are off loaded at the piling machines from where they are lifted by overhead cranes and kept in stock yard.

2.3 DESCRIPTION OF THE ELECTRICAL WORKING SCHEME

The speed of coiler motor is automatically synchronised with stand no.23. Manual operation of the motor by switch K is only used for testing and adjustment purposes.

2.3.1 General Principle of Working (Ref. Fig. 2.4)

Speed of the coiler motor meant for a particular strand is controlled by only varying the generator voltage feeding it, the field of motor is always constant and is fed from 220V d.c. supply.

Now the generator voltage is varied only by changing its excitation. The excitation of the generator gets supply from amplidyne. Depending upon the output voltage of the amplidyne, the voltage of the generator will vary. Output of the amplidyne is controlled by its own windings(control), reference wdg OII_1 - OII_2, motor current feed back wdg OI_1-OII_2 and stabilizing wdg $OIII_1$ - $OIII_2$. Reference wdg of the amplidyne is fed from a magnetic amplifier MY whose output is controlled by six of its control windings. Winding Y_{11}-Y_{12} is fed from Aux. Magnetic Amplifier PMY which amplifies signal from the tachogenerator of the stand with which the coiler is to be synchronised. Winding Y_{21} - Y_{22} is a flexible feed back winding giving feed back depending upon output voltage of Amplidyne. Winding Y_{31}=Y_{32} is stabilizing winding connected in bridge across the output of the amplidyne. Y_{41} - Y_{42} is self-suppressing winding. It works only during

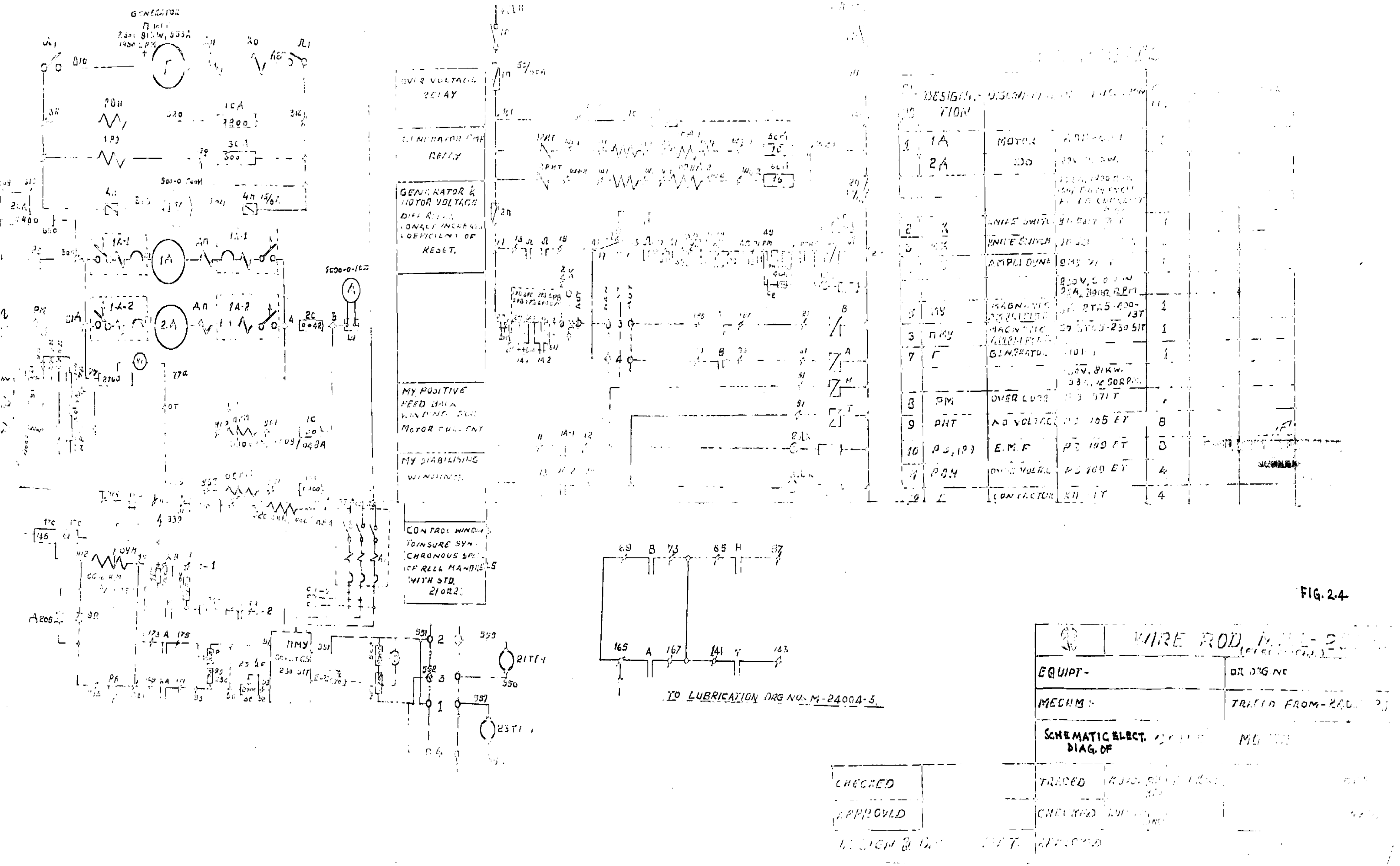
GENERATOR
OVER VOLTAGE RELAY
GENERATOR & MOTOR VOLTAGE
KESET.
MY POSITIVE FEED BACK
MY STABILISING
CONTROL WINDG TO INSURE SYN-CHRONOUS SPEED OF REEL MANDRELS WITH STD.
DESIGNATION
MOTOR
KNIFE SWITCH
AMPLIDYNE
GENERATOR
OVER CURR
E.M.F
CONTACTOR
TO LUBRICATION DRG NO. M-24004-5.
WIRE ROD
EQUIPT -
MECHM :
SCHEMATIC ELECT. DIAG. OF
TRACED
CHECKED
APPROVED
TRACED FROM-

FIG. 2.4

stoppage of the motor and serves to kill the output of MY which ultimately brings down the generator voltage suddenly because the output of the amplidyne suddenly falls through its reference winding. Winding $Y_{51} - Y_{52}$ of the MY is stabilizing winding for the fluctuations of the generator voltage. $Y_{61} - Y_{62}$ is positive feedback winding for motor current.

The whole system has got high amplification factor, due to presence of two amplifying units i.e. Magnetic Amplifier and Amplidyne. To increase the generator voltage from 92V (for rolling speed of 12 M/sec) to 230 V (for rolling speed of 30 M/sec), the output of the magnetic amplifier changes from 0.39 to 0.45 Amp. only.

2.3.2 Working of Scheme

Knife siwtch 'M' is closed and switch 'K' is put in zero position and stand selecting switch in 21st or 23rd position as desired. Air circuit breakers for IA-1 and IA-2 for motors are switched on. Then ACB-3A and ACB-AB are switched on. Now the contactor will pickup as soon as the drive for generator, drive for amplidyne is started and lubrication system for the motor starts working.

Now switch 'K' is put in Automatic, contactor 'A' picksup and the auxiliary contacts of the same close thereby feeding the output of Auxiliary Mag. amplifier PMY to the winding $Y_{11}-Y_{12}$ of the Mag. amplifier MY. This output of MY appears across wdg OII_1 - OII_2 and is much more than required, during normal working. Thus during starting Amplidyne output voltage is very high resulting in corresponding high voltage from the generator. Because the contactor is already closed, the Motor start with great acceleration and draw quite heavy current. As the motor picks up speed automatically the amplidyne voltage is brought down firstly by reducting the MY output and secondly by current feedback wdg. of MY. Output of MY is reduced mainly by voltage feedback wdg. Y_{21} - Y_{22}. Positive current feedback winding Y_{61} - Y_{62} only helps little to maintain the output of MY.

The output of PMY is mainly reduced by the current feed back wdg. OI_1 - OI_2. The effect of this winding is too much when the motor takes a high starting current and reduces thereafter. Thus the output of amplidyne comes to normal value which gives a particular output for the generator required for that particular speed of rolling.

Stoppage of motor is done by switch 'K' by bringing it to zero position.

2.4 INTERLOCKINGS

Motor will not start if :

(a) the lubrication system is not started

(b) the drive of MY is not started

(c) the drive of generator is not started.

(d) ACB-3A of stabilizing voltage is not closed.

(e) ACB-AB of 400 V AC supply to MY is not closed.

Above interlockings are provided for the safe and proper running of equipments. If any of the above conditions are not satisfied, the coiler motor cannot be started without bypassing the interlocking which in any case is not desirable.

2.5 EXPERIMENTAL PERFORMANCE OF THE MILL

It has been observed that finished coils width varies in the range of 200 - 250 mm not utilizing the full space provided between the **inner** and outer fingers. The change in coiler speed is very less ± 50 rpm according to the 23rd stand speed variations. This results in the high piling of the coils with increased height for a particular length and dia. of rod rolled. This not only fails to utilize the storage yard area optimally, but also affects the efficiency of the mill. by causing delay in the process.

Apart from the non-closeness of **wire-rod loops** the back end projections are more - 300 mm to 500 mm causing inconvenience in handling and loss of metal.

2.6 NECESSARY MODIFICATIONS REQUIRED

As it is clear from the performance characteristics of the mill the space between two fingers should be sufficiently utilized for getting compact coils. The wire rod loops being formed should fall as close to each other as possible completing the layer.

The back end projections need to be minimised further to avoid delay, inconvenience in the transportation. In addition this will reduce the end losses and improve commercial acceptability of the product.

CHAPTER - 3

MICROPROCESSOR BASED CONTROL SYSTEM

3.1 WHY MICROPROCESSOR CONTROL ?

The advent of microprocessors and further advances in microelectronics have opened a new vista in electronic control applications. Complex control functions such as those associated with thyristor fed motor drives are now realized advantageously with systems built around microprocessors. The generation of complex ~~cartonary and~~ need of fast decision taking capabilities at different stages depending upon various parameters in process makes other logic circuits design more complicated and unreliable. This is because of a number of external components and too many interconnections as compared with the system based on microprocessor. The microprocessor based control system gives high degree of flexibility. Also, the system development time and cost is considerably reduced because soft-ware modifications can be easily effected unlike hard-ware changes.[9,10]

3.2 ORGANISATION OF THE MICROPROCESSOR

The 8085 is an 8-bit microprocessor available as a pin DIP. As shown in Fig. 3.1 the data bus is 8 bits wide which implies that 8 bits (1 byte) of data can be transferred to or from the 8085 in parallel. There are 8 pins which are dedicated to ~~transmit~~ the most significant 8 bits of the memory address. The least significant 8 bits of the address are transmitted on the 8 lines on which data is transmitted. Thus, the data and part of the address are transmitted over a set of shared lines. This is done by multiplexing technique. Obviously that the data and address (least significant 8 bits) are transmitted at different points in time.

Thus effectively, the 8085 has a 16 bit address transmission capability. This implies that a total of 2^{16}(=65536) memory locations can be addressed directly by 8085. Each location is a byte as 8 bits of data is transferred in parallel between the 8085 and the memory. Therefore, we say that the 8085 can directly address 64 K bytes of memory.

Inside the 8085 there are several registers which are used during the execution of a program. (Refer Fig.3.2).

There is one 8-bit register known as the accumulator (abbreviated as ACC). It is used in various arithmetic and logical operations. For example, during the addition of two 8-bit integers, one of the operands must be in the accumulator. The other may be either in the memory or in one of the other registers.

There are six general purpose 8-bit registers that can be used by a programmer for a variety of purposes. These registers are labelled as B, C, D, H and L. They can be used individually (e.g. when operation on 8-bit data is

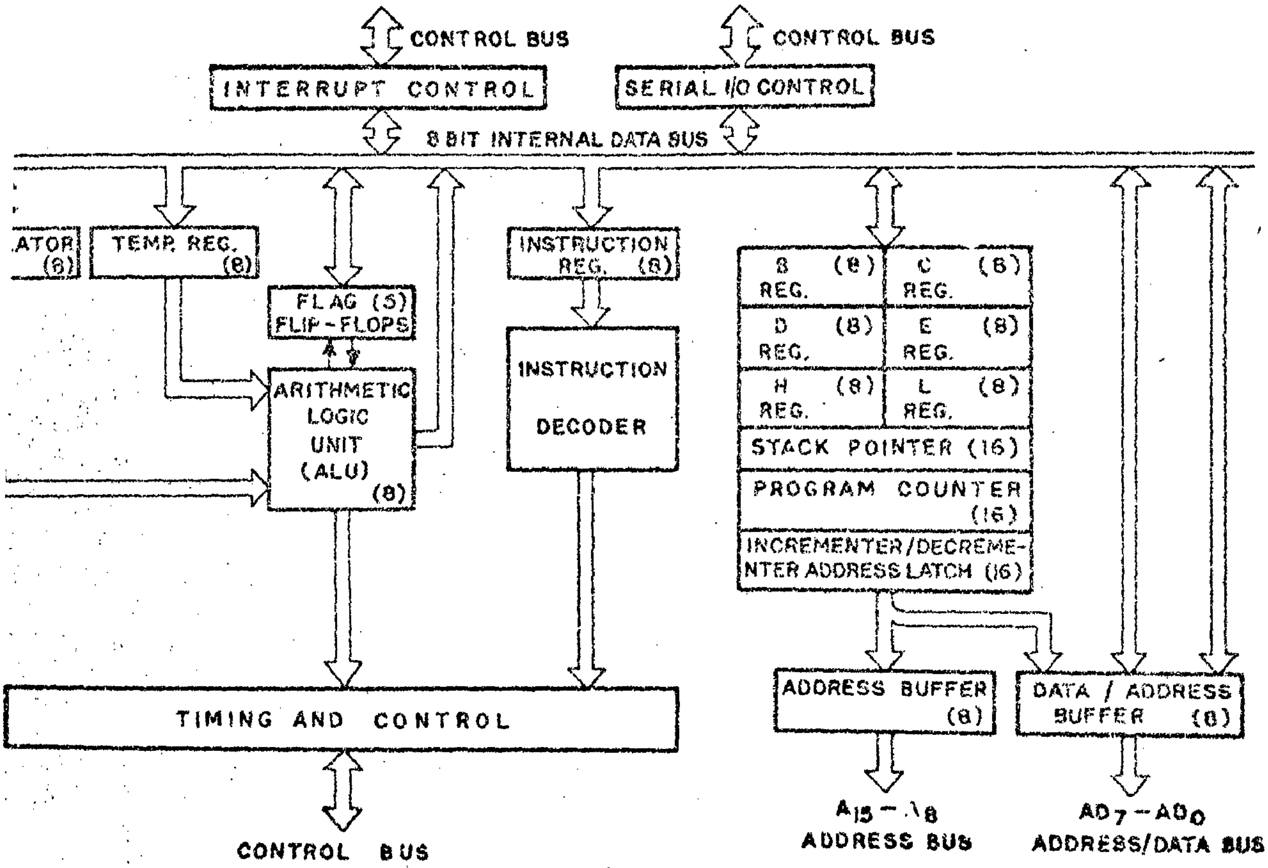

Fig. 3.2: Functional organization of the 8085

desired) or in pairs (e.g. when a 16-bit address is to be stored). When used in pairs, only the combinations B-C, D-E, H-L are permitted. Bit patterns are designated to refer to register pairs or individually in an instruction.

There is a 16-bit register which is used by the 8085 to keep track of the address of the instruction (in the memory) that has to be executed next. This register is called the program counter (abbreviated as PC). The contents of the program counter are automatically updated by the 8085 during the execution of an instruction so that at the end of execution of this instruction it points to the address of the next instruction in the memory. 16 bits of address are sent out by the 8085 on the address and data bus, in some instances the PC holds this address before it is transmitted.

There is an another 16 bit register, known as stack-pointer (abbreviated as SP). It is used to maintain a stack in the memory. A set of five flip-flops, one-bit registers, serve as flags. These registers indicate certain conditions (e.g. overflow, carry) that arise during arithmetic and logical operations.

Arithmetic and Logic Unit (ALU) performs arithmetical logical and rotate operations. Registers which function with the ALU include an 8-bit accumulator, an 8 bit temporary register and a 5-bit flag register.

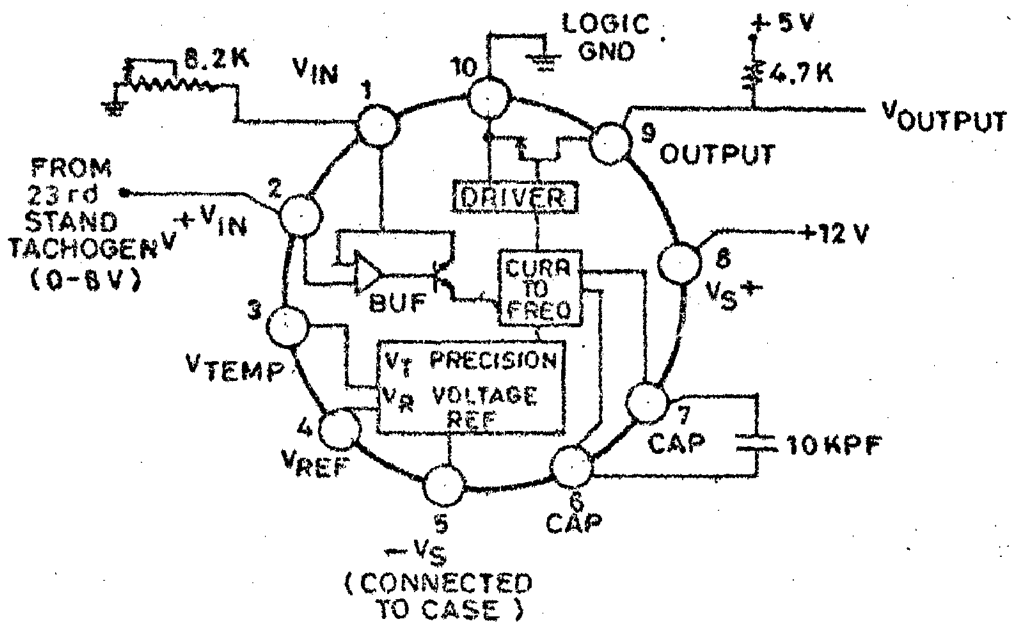

FIG.3.3.AD-537 TO-100 PACKAGE

Instruction register, an 8-bit register, transfers information from the internal bus to the instruction decode and control section. The output of the decoder combined with timing signals from the timing and state control section, provides control signals for memory, ALU and data bus buffer.

The 8085 has five interrupt lines, namely TRAP, RST7.5, RST 6.5, RST 5.5 and INTR. Activating any of these lines causes the μP to suspend the normal sequence of instruction execution and execute the next instruction either from a fixed location in the memory (Table - I) or execute a CALL instruction jammed onto its busses by some external device. The CALL instruction is executed if INTR line goes high. When any of these five lines goes high, we say that an interrupt has occurred. Interrupts are used by I/O devices to transfer data to or from μP without wasting much of its time.

Table I - Interrupt Restart Locations for 8085

Line	Location from which next instruction is picked up (hex. address)
TRAP	24
RST 5.5	2C (= 5.5 x 8)
RST 6.5	3H (= 6.5 x 8)
RST 7.5	3C (= 7.5 x 8)

3.3.1 MICROCOMPUTER CONTROL SYSTEM COMPONENTS

3.3.1 AD-537 CHIP

A block diagram of the AD 537, TO-100 package is shown in the Fig. 3.3. A versatile operational amplifier (BUF) serves as the input stage, its purpose is to convert and scale the input voltage signal to a drive current in the NPN follower. The drive current to the current-to-frequency converter (an astable multivibrator) provides both the bias levels and the charging current to the externally connected timing capacitor. The square wave oscillator output goes to the output driver which provides a floating base drive to the NPN power transistor. This floating drive allows the logic interface to be referenced to a different level than $- V_s$. The reference generator is to provide the reference and bias levels for the amplifier and oscillator stages.

23rd stand tachogenerator output (0-8 V) is connected to the Pin 2. Capacitor (Polystyrene) of 10 KPF is connected between the pins 6 and 7. Output is taken from the pin no.9 as shown in the figure. 3.3.

3.3.2 AD-571 Chip (Ref. to Fig. 3.4).

AD-571 Chip is a 10 bit successive approximation A/D converter consisting of a DAC, voltage reference, clock, comparator, successive approximation register and output buffers all fabricated on a single chip. No external

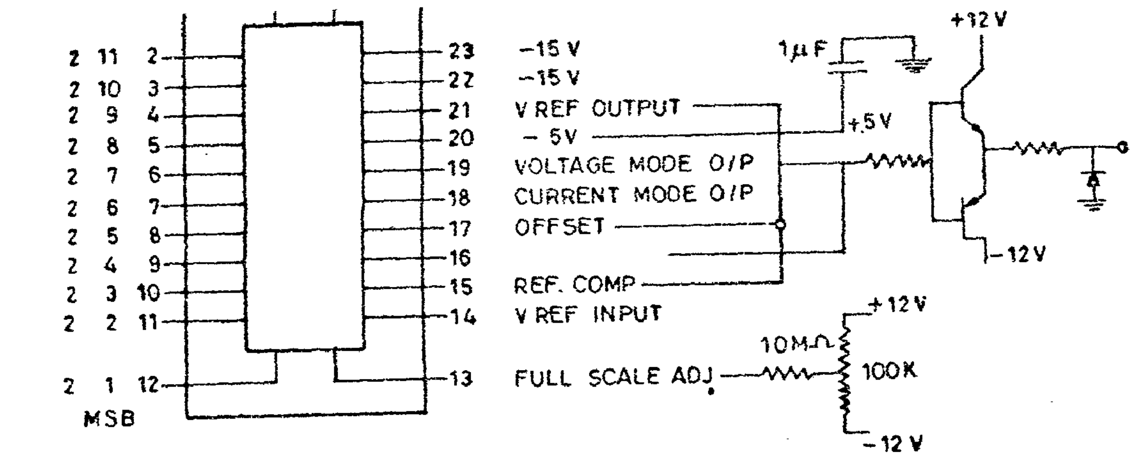

FIG.3.5. D/A CONVERTER CHIP DAC 1200

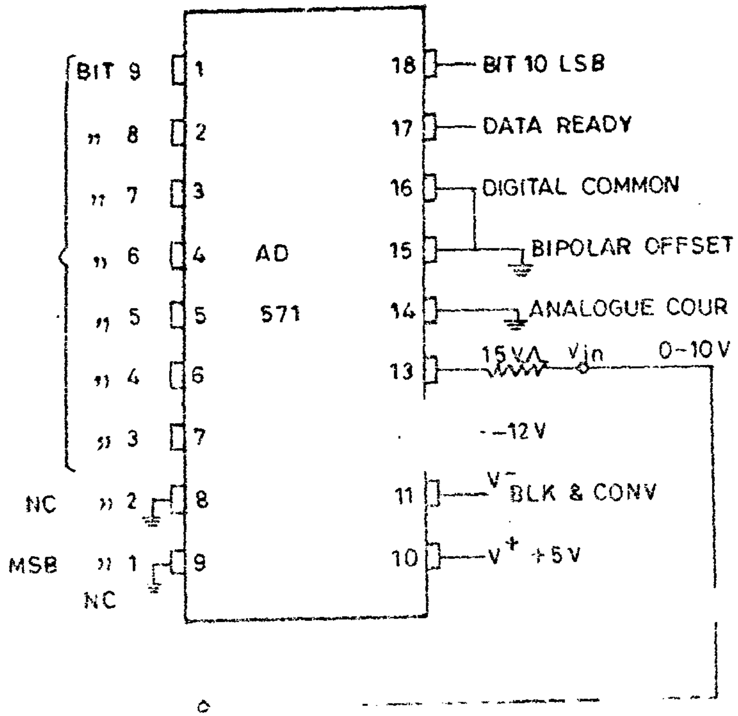

FIG.3.4. A/D CONVERTER CHIP

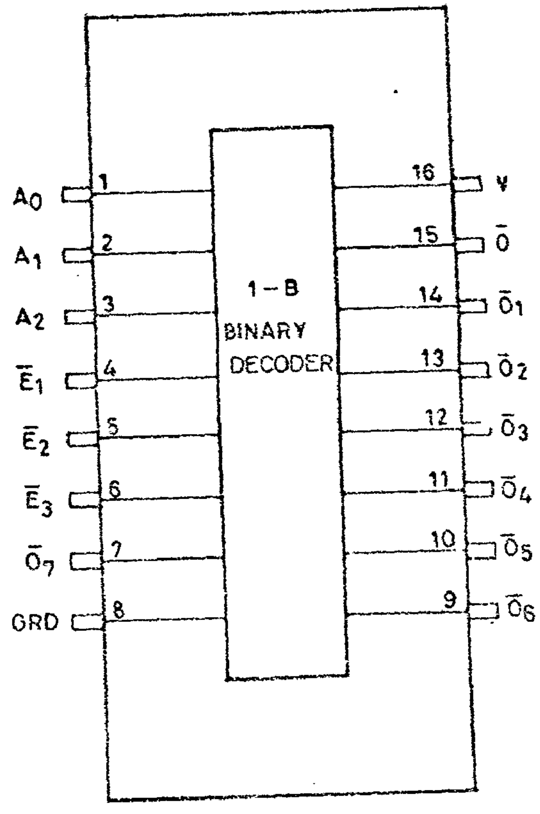

FIG.3.6. DECODER CHIP 3205

components are required to perform a full accuracy 10 bit conversion in 25 μs. It operates on supplies + 5 V, + 15 V and -12 V on pins 10, 13 and 12 respectively and accepts analog input of 0 to + 10V in pin no.14 from the tacho-generator of coiler motor.

As the BLANK and CONVERT input is driven low, the three state outputs will be open and conversion will commence. Upon completion of the conversion, the DATA READY line will go low and the data will appear at the output. This converter executes a true 10-bit conversion with no missing codes in approximately 25 μs.[5]

3.3.3 Digital to Analog Converter (DAC 1200) Chip

DAC 1200 converter completely low cost converter, is a complete functional block requiring only application of power for operation. It combines a precision 12 bit weighted current source (12 current switches and 12 bit thin film resistor network), a rapid setting amplifier, and 10.24 V buffered reference. A logic low ($\leq$ 0.8 V) turns a given bit 'ON' and a logic high ($\geq$ 2.0 V) turns the bit OFF. Supply + 5 V, + 15V, -15V is connected to pin nos. 20, 22, 23. Analog output is taken from pin 19 in voltage mode as shown in Fig. 3.5.

3.3.4 Binary Decoder (3205 CHIP) (Refer to Fig.3.6).

It is one out of eight binary decoder in 16-Pin DIP form. When the 3205 is enabled, one of its eight output goes 'low', thus a single row of a memory system is selected. The 3 chip enable inputs on the 3205 allow easy memory expansion if required in future stage[5] This decoder is used to select memory chips 8355, 8755 and 8155.

3.4 METHOD OF CLOSE LAYING OF WIRE RODS

Constancy of material flow dictates that the coiler speed $\omega(t)$ at any time be related to rolling speed 'V' as follows :

$$\omega(t).r = V$$

The coiler speed therefore

$$\omega(t) = V/r \qquad \ldots (1)$$

The rolling speed (or metal delivery speed) corresponds to actual speed of rolling and is calculated from the last rolling Stand in terms of VCO frequency.

If r_o = outer radius of the coil

r_i = inner radius of the coil

L = length in one layer

Following equations can be written :

$$d\ell = r . d\theta$$

$$dr = K . d\theta$$

so $\frac{d\ell}{dr} = \frac{r}{K}$

and $\ell = \frac{1}{2k} r + \ell_o$ ... (2)

From the initial and final conditions the values of ℓ_o and K are determined as follows :

At $r = r_i$ $\ell = 0$

At $r = r_o$ $\ell = L$

Putting above values in eqn.(2) we get

$$0 = \frac{1}{2K} r_i + \ell_o \quad \ldots (3)$$

$$L = \frac{1}{2K} r_o + \ell_o \quad \ldots (4)$$

Solving above equations we get

$$L = \frac{1}{2K} (r_o - r_i)$$

$$\ell_o = - \frac{r_i^2 . L}{r_o^2 - r_i^2} = \frac{r_i^2 L}{r_i^2 - r_o^2} \quad \ldots (5)$$

From equations (3) and (5) we get

$$\ell = \frac{L r^2}{r_o^2 - r_i^2} + \frac{r_i^2 L}{r_i^2 - r_o^2}$$

or $$r^2 = r_i^2 + \frac{\ell}{L}(r_o^2 - r_i^2) \qquad \ldots (6)$$

Metal deflected through the cone during time 't' is given below :

$$\ell(t) = f\,[\omega(t),\ r(t),\ R,\ r_d,\ \theta,\ T] \qquad \ldots (7)$$

where $\omega(t)$ = angular speed of the cone

r_d = rod dia.

$r(t)$ = radius of the coil laid

R = radius of the cone at the time = 1170 mm

θ = angle of deflection of the rod from the rim of cone (116^o)

T = time for laying one layer

At any time 't' the length of metal delivered is given by

$$\ell(t) = \int_o^t V_{del}.dt \qquad \ldots (8)$$

For any time 't', necessary length being laid and its radius of laying are determined from eqns. 6 and 8. After due substitutions in the linearized eqn. (7) necessary cone speed $\omega(t)$ and time duration are evaluated.

For the cone speed $\omega(t)$, corresponding voltage reference for dual converter is determined and computed by the microcomputer.

Table 3.1 shows the values of coiled motor speed, cone speed and Time for each **cycles** for 8 mm of wire rod when rolled at 27 M/sec of rolling speed.

BLE 3.1 : SHOWING RELATIONSHIP BETWEEN ROLLING PARAMETERS
(For 8 mm dia. of rod & 27 M/sec. speed)

N (cycle)	Time T(N)	Cone speed W(N)	Motor Speed in RPM (N)
1	2	3	4
1	0.105597	59.4714	1215.6
2	0.107458	58.4416	1194.5
3	0.109318	57.4468	1174.2
4	0.111179	56.4854	1154.6
5	0.113040	55.5556	1135.6
6	0.114901	54.6559	1117.2
7	0.116761	53.7849	1099.4
8	0.118622	52.9412	1082.1
9	0.120483	52.1236	1065.4
10	0.122344	51.3308	1049.2
11	0.124204	50.5618	1033.5
12	0.126065	49.8155	1018.2
13	0.127926	49.0909	1003.4
14	0.129787	48.3871	989.0
15	0.131647	47.7032	975.1
16	0.133608	47.0383	961.5
17	0.135369	46.3918	948.2
18	0.137230	45.7627	935.4
19	0.139090	45.1505	922.9

1	2	3	4
20	0.142612	44.5545	910.7
21	0.144673	43.9739	898.8
22	0.146533	43.4084	887.3
23	0.148394	42.8571	876.0
24	0.152115	42.3197	865.0
25	0.153976	41.7957	854.3
26	0.152115	41.2844	843.9
27	0.153976	40.7855	833.7
28	0.155837	40.2985	823.7
29	0.157698	39.8230	814.0
30	0.159558	39.3586	804.5
31	0.161419	38.9049	795.2

The values in Table are calculated from the equation (7) using the values of $\gamma(t)$ and r from eqns. (6) and (8) considering various dynamical forces and roll pass design factors. Various assumptions are made at different stages for different cross section of the wire rod laid so finally it does not end into a particular equation. Therefore values are taken from intermediate stages also for computation purpose in the tabular form.

3.5 NEW THYRISTORISED DRIVE FOR COILER MOTOR

3.5.1 Speed Control Scheme for Coiler Motor

Fig. 3.7 shows the block diagram of the scheme for speed control of coiler motor. The error voltage signal proportional to $(\omega_o - \omega_m)$, where ω_o is the reference speed, is passed through a PI (proportional - integral) controller block. This provides a reference signal e_1 for the motor current and the difference between e_1 and the motor current i_a is passed through a second PI block. The first PI control ensures that the steady state error in speed will be zero. The second controller provides the current limit. The maximum value of the motor current will be limited by the output voltage e_1 of the first PI controller. The proportional part is used to improve the response time of the controlled system. The integration will result in a non-zero output evenwhen the input goes to zero[3] This will produce zero static error with step inputs to the control system. The

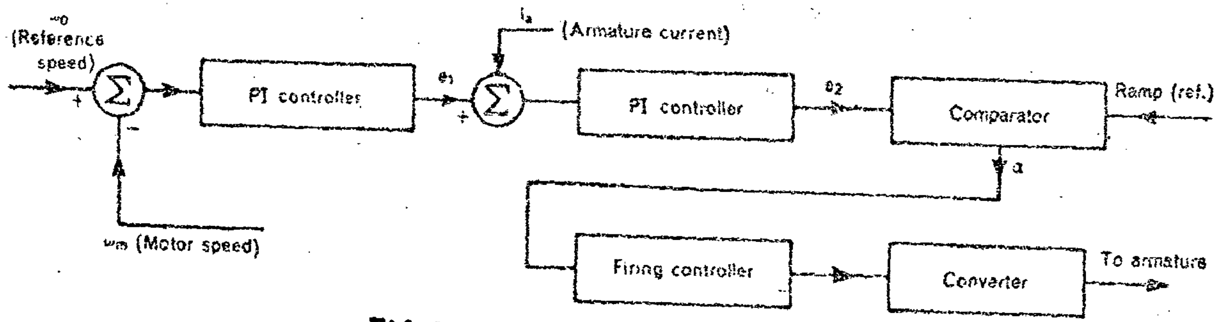

FIG. 3.7 Block diagram of controller – thyristor

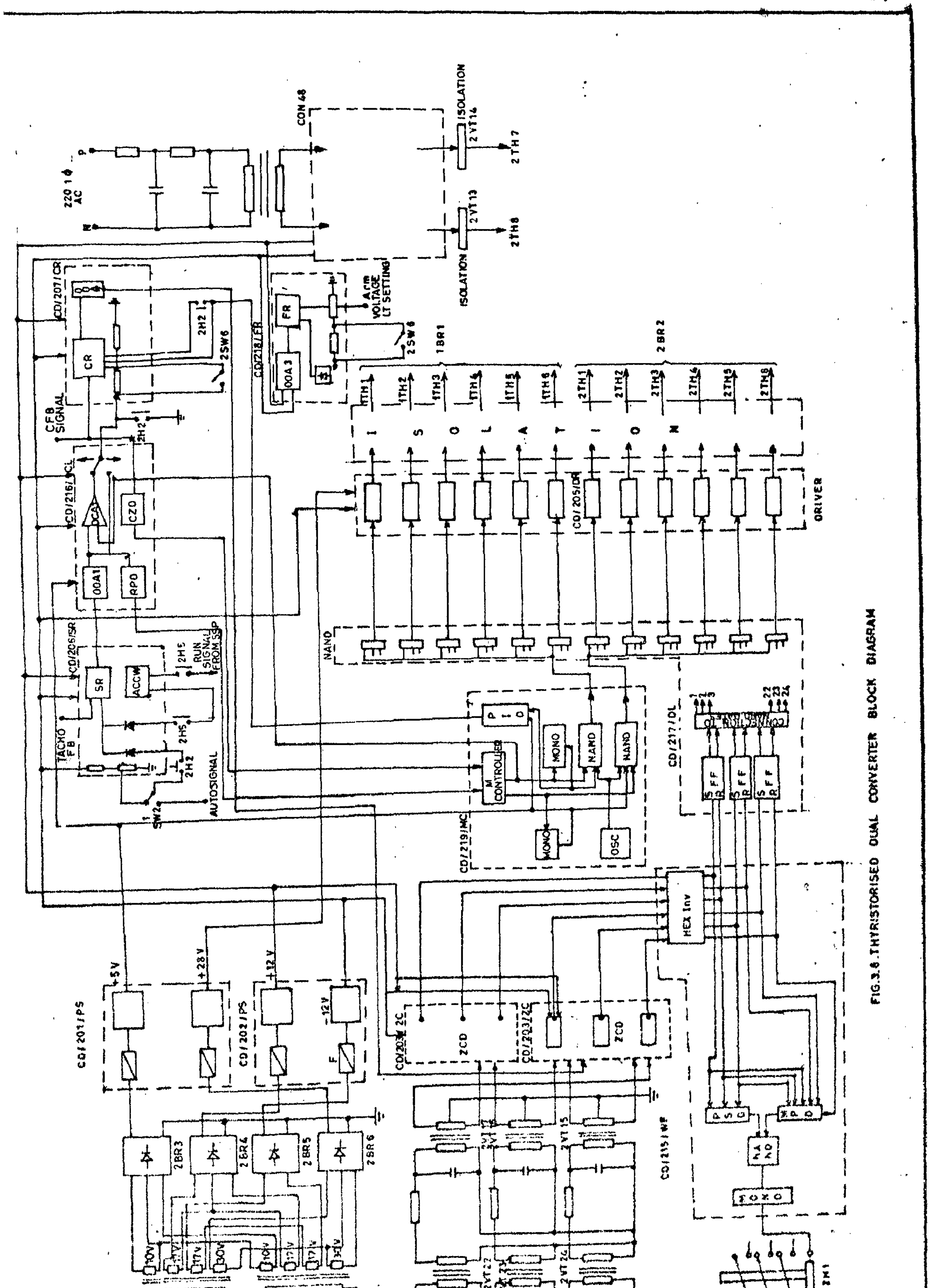

FIG.3.8 THYRISTORISED DUAL CONVERTER BLOCK DIAGRAM

output voltage e_2 of the second PI block is compared with a ramp to obtain the instant of firing the SCR's. For triggering the SCR's in a sequence, firing controller block is used. The current feedback improves the dynamic response of the system against variations in the supply voltage.[8]

3.5.2 Dual Converter (Ref. to Fig. 3.8.)

1 ∅ half controlled bridge gives 220 V dc (nominal) constant to the field for operation below base speed and controlled DC voltage below 220 V dc for operation above the base speed actual value depending on speed demand signal. A current sensing type field loss protection circuit provides protection against the loss or undue weakening of field.

There are potentiometers for adjusting the amount of feedback signals, like armature current, tachogenerator O/P and armature voltage.

Six thyristors in each of the two bridge config. of dual convertor are supplied by 3 ∅ in RYB sequence. Each thyristor is to be given gate pulses adjustable over a period of time which should synchronise with its anode cathode voltage. 2 VT15,16,17 are synchronising Xers for this purpose. The RC lag network in each phase filters the incoming supply and gives phase lag of 60°. 2 VT18,19 are power supply xers, the sec voltage of which are rectified and fed to the electronic power supply cards CD/201/PS and CD/202/PS. The former generates +5 Vdc supply for digital

IC's using IC regulator and + 28V for the drives stages using transistor regulator circuit. The later (CD/202/PS) also uses the rectified input, however, to give highly stabilized +12 V and -12V dc supplies using integrated circuit stabilizers. Both these power supply cards provide necessary dc supply to other electronic control cards and also give stabilised ref. for manual mode speed ref. [4]

Speed demand signal (either in Auto mode or manual mode) is compared with the tacho f.b. signal in the card CD/206/SR and error is amplified. However, this card output is limited to excursions only on negative side so as not to charge the electrolytic condensers in reverse direction. However such undesired reverse, charging is inevitably called for during 'regeneration' requirements. This necessitated converting the 0 to - 6.2 V dc O/P of SR card to -6.2 to + 6.2 V dc excursion so that 0 to -6.2 V dc correspond to functioning of the forward converter and 0 to + 6.2 V dc to that of the reverse. This is done by feeding 0 to -6.2 V dc O/P of SR card to the card CD/216/CL for being off-setted to a value -6.2 V to + 6.2 V dc.

The current f.b. and current ref. signals which are compared and amplified in CD/207/CR card always required to be of +ve and -ve polarities respectively irrespective of wheather forward or reverse converter is in operation. The requirement is met by digitally controlled analog inverter

(DCAI) of CD/216/CL card, which changes its state from non-inverting amplifier to inverting amplifier and vice versa, whenever a call is made to change the operation from forward to Rev. converter and vice versa respectively. Such a call for change is given by the O/P of 'Master Controller' in card CD/219/MC, at one of the inputs of DCAI. The Master controller O/P in turn is decided by the outputs of reference polarity detector (RPD) and CZD of card CD/216/CL.

The current reglr. amplifier (CD/207/CR) output varies from 0 to + 10 V d.c. which is offsetted to give -10V to +10V dc excursion which forms the 'control voltage' signal for cards CD/203/ZC and decides the firing instant for thyristors.

The ZCD (CD/203/ZC) process the phase shifted and stopped down phase voltage to generate firing pulses (six channels) for thyristors at a proper instant of time depending on the control voltage signal. The O/P pulses from these cards (a) CD/215/WF and (b) CD/217/DL.

Output of channels 1, 3, 5 of CD/203/ZC cards are fed to the phase sequence detector (PSD) of CD/215/WF output of which is 'high' for correct input phase sequence and periodically changing 'high-low' for wrong input phase sequence. Also, all the six channel outputs of CD/203/ZC are fed to the Missing Pulse Detector (MPD) circuit of CD/215/WF output of which is 'high' for no pulse missing and changing 'high low' for any of the pulse missing. The O/P of PSD and MPD are given to a NAND gate which drives a mono under healthy condition (i.e. correct phase sequence and no pulse missing) output of 'NAND' is '0' and so is the 'Mono' output and hence relay $2H_1$ is not energized. However, under fault condition, O/P of NAND and hence that of Mono toggles between 'high-low' states. The filter and a driver stage at the O/P side of Mono drives the relay.

Moreover, the O/P pulses from 6 channels of ZCD card are given through WF card to the set and reset inputs of three FF's in card CD/217/DL. This card also has 12 nos. of three input NAND gates (six for each converter). The FF outputs are mixed in proper combination by using these gates, to get the required 120° wide firing pulses. A 15 KHz carrier signal from CD/219/MC modulate these pulses and form the third input of the NAND gates in the Dual converter logic card (CD/217/DL).

The said 120° firing pulses generated in CD/217/DL, are weak and their power level needs to be raised. This is done in cards CD/205/DR. Each of these two cards (one of each converter) has six channels, one for each thyristor in a converter and their O/P drive the corresponding thyristor gate via pulsers used for isolating these channels.

The M/controller card CD/219/MC decides which particular converter (For. or Rev.) should get the firing pulses, other being blocked at that time. Moreover it also blocks pulses for 22 m sec to both the converters whenever a change over from one converter to other is demanded.

3.5.2.1
Description of Changeover Sequence :

The O/P of speed reglr. is true representation of system torque requirements, to keep speed error zero. Hence this is made the basis for changeover from motoring to regeneration and vice versa. For safe changeover it is necessary to ensure the zero current condition. Thus the logic circuits decide to changeover when current becomes zero, 'after the reference for current' has changed its sign. This ensures proper stable operation in either mode with discontinuous current. After the changeover decision is taken pulses to the outgoing converter are removed, control voltage is reset to -10V and a current signal is injected, to discharge the Pl components rapidly, for 20 m sec. After these 20 m sec. pulses are released to the second converter to establish the required current which is controlled by the current regulator[4]

3.5.3 Protection

Various components and equipments as a whole have to be protected adequately for excessive currents due to abnormal conditions. Again thyristors being very sensitive to voltage surges, have to be adequately protected for voltage surges in AC main lines. This is adequately provided by the card CD/210/SL in Assembly No.5 (Panel I) with its associated components.

To avoid misfiring of thyristors (i.e. firing them at undesired instant of time), proper phase sequencing of the incoming supply lines is essential. The inbuilt phase sequence sensing and single phasing sensing electronic scheme (Card CD/215/WF) alongwith the associated interlocking scheme provide adequate protection to the equipments against wrong phase sequence input and against the loss of pulses during single phasing.

Thyristors have very small heat capacity and hence have practically no transient overload rating. Therefore, they have to be protected by specially made fast acting fuses having less heat storing capacity (referred to as I^2t value) than the thyristors. Therefore - In no case the fuses for thyristor protection should be replaced by any other HRC fuses, than the specified.

The fast acting, built in current limit in the electronic control scheme very effectively prevents excessive current.

Three fuses in AC lines and DC link fuse are additional protection.

The CT operated bimetallic thermal O/L relay $2OL_1$(settable range) in the AC supply lines provide non-destructive tripping of the drive against overloads.

Protection of thyristors against device turn-on and commutation surges is provided by an R-C combination(snubbers) connected across each thyristor. A series impedance is required for all these snubbers to be effective, which is provided by the leakage reactance of the main line power transformer (3VT1). Regenerating bridge (1BR1) requires additional leg choke in series with each of the thyristors for effective protection against dV/dt across them.

If the field of a DC motor is unduly weakened and normal armature current is passed, it would race up to undesirable high speed and get damaged, particularly if it is not loaded. With field absent similar thing can happen due to residual magnetism. To protect against such hazards motor field circuit has a current sensing type field loss detection relay, which trips the drive for the loss or undue weakening of the field.

Wiring bunches of the installation are protected by control fuses. Field supply is protected by fuses[4]

3.6 FLOW CHART OF MAIN PROGRAMME

For bringing the microcomputer system into operation, stack pointer and I/O ports are initialised and interrupts 6.5 and 7.5 are enabled. Micro-computer senses the metal present pulse through photo sensor signal (PS16) and reads VCO output pulses. If metal is not present, the microcomputer continues to output zero volts, otherwise in presence of metal it outputs zero volt for τ_d sec., the time needed by the metal to reach coiler which is 1.5 sec. for 8 mm wire rod if being rolled. Then microprocessor reads voltage V(K) and no. of pulses N(K) from look up table stored in the RAM and outputs reference voltage V(K) volts for N(K) number of pulses duration. It goes on incrementing the value of 'K' - the no. of segment, till it reaches the value of 31. Here one cycle of coiling operation gets completed forming two layers of wire rod loops. In the same way further cycles are completed till the microprocessor gets interrupt signal from PS-16 photo-sensor.

TABLE 3.2 : MICROCOMPUTER SIGNAL PARAMETERS

Address	Data	Description
2875	05	Initial delay after PS16 goes high
2876	08	Step height for normal catenary (0.625 V)
2877	40	Maximum positive voltage of catenary (5V)
2878	CO (+ve slope)	Maximum negative voltage of catenary (-5V)
2879	80	Initial voltage outputted during RST 6.5 back end
287A	FF	Delay number of the initial back end voltage (6.5)
287B	50	Maximum value of back end voltage (6.5)
287C	20	Step height value during 6.5 back end
287D	FF	Delay number during each step output during 6.5 Back end
287E	FF	Delay number while outputting maximum backend voltage (6.5)
287F	FF (- slope)	Delay number while outputting zero volts during 6.5 Back end
2880	AO	Initial voltage outputting during RST 7.5 Back end.
2881	FF	Delay number of the initial back end voltage(7.5)
2882	CO	Maximum value of Back end voltage
2883	10	Step height value during 7.5 Back end
2884	FF	Delay number during each step output during 7.5 Back end
2885	FF	Delay number while outputting maximum back end voltage (7.5)
2886	FF	Delay number while outputting zero volts during 7.5 back end.

TABLE 3.3 : 288F - LOOK-UP TABLE

2890	4C 00	DO
92	50 00	CE
94	55 00	CC
96	5A 00	CA
98	60 00	C8
9A	67 00	C6
9C	6F 00	C4
9E	78 00	C2
A0	84 00	C0
A2	92 00	BE
A4	A4 00	BC
A6	BC 00	BA
A8	D3 00	B8
AA	10 01	B6
AC	73 01	B4
AE	B1 03	28B2
B0	B1 03	28B0
20C8	C3 93	08
20CE	C3 0A	09

3.7 ENTIRE CONTROLLER SYSTEM

Fig. 3.10 shows the general layout of the control scheme showing the coiler motor driven by the thyristorised dual converter, whose reference is fed by the microcomputer as per the algorithm. The coiler motor speed varies linearly in accordance with the reference signal, such fast reference with maximum allowable delay of 200 m secs. has been achieved with two feed back loops in drive control system i.e. current feed back in minor loop and speed (tachogenerator) feedback in outer loop as shown in Fig. 3.7. This ensures fast and reliable operation of the thyristorised dual converter in both motoring and regenerative modes of operation.

The control signal generated by the microcomputer, is repeatitive and cyclic in nature. Each cycle controls laying of two layers of wire rods and cone speed is increased during laying of the wire from drum periphery to its centre (i.e. coil turn diameter is getting decreased continuously) and is decreased when laying the second layer from centre to the periphery of the coiler drum (turn diameter increases)..

Each layer of the coil is laid in 16 segments. The required reference value and its duration for each segment are determined from equations 6, 7 and 8 and fed to the dual converter by the computer. Metal delivery speed 'V_{del}' corresponds to the actual speed of rolling and is calculated from the last rolling standreference in terms of frequency

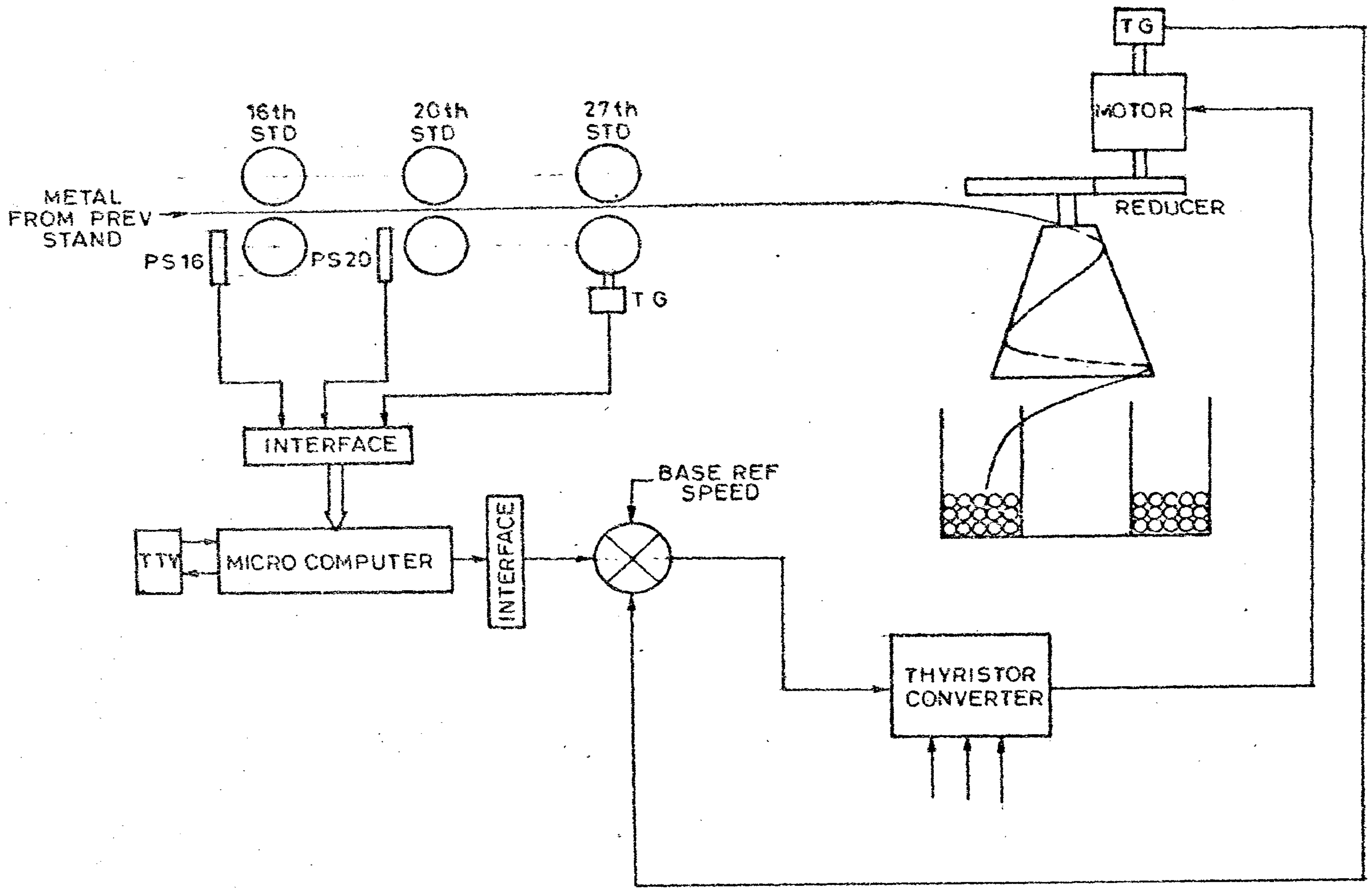

FIG.3.10.CONTROLLER SYSTEM

of the VCO (voltage controlled oscillator). The reference of last rolling speed constitute the base speed of the coiler on which the cyclic variation of the computer signal is superimposed.

Thus the coiler motor speed varies ± 200 rpm around mean base speed. The duration of computer reference for each segment of laying is expressed as number of pulses of VCO output and stored in the form of look-up table alike reference values. Computer reads them and outputs as per the algorithm. Due to any reason, if the computer reference is not available, the coiler motor will lay coils as per the mean base speed of last rolling stand without causing any operating inconvenience.

The microcomputer outputs zero volt when the metal is not present. As soon as the front end of the metal is detected through photocell- sensor-16(PS16), computer continues to output zero volts for τ_d secs, the time which is necessary for the front end to travel upto coiler cone, after which computer outputs a voltage of $V_{ref}(K)$ for N(K) number of VCO pulses which are read from respective look up tables, 'K' being the segment number. The process of laying continues until the back-end is detected by PS-16 which through its falling edge of the pulse, interrupts the processor and outputs initial part of the back-end program. When the back end is detected by PS-20, the running back-end program is further interrupted and final part of the backend program is outputted such that back-end is perfectly laid. The PS20 interrupt has higher priority to PS-16 interrupt.

CHAPTER - 4

EXPERIMENTAL TEST PROCEDURE

All the drives of different equipments including coiler are made - ON before the rolling takes place. After getting clearance from the mill operation put it in the form of visual signal (GREEN), the micro-computer system is started. As the μc gets signals from photo sensor it starts generating the signal as per the soft ware programs.

The signal nature is checked on the CRO and if any malfunctioning is there, corrections are made. In fact, the output signal of microcomputer is checked prior to the actual rolling takes place by giving artificial signal for metal reaching the stand (as the photosensor would give in case of actual rolling) by switching on a toggle switch provided for the purpose.

The maximum and minimum speed of the coiler motor is recorded for a particular diameter of the rod being rolled also various time delays - initial and back ends are recorded.

The end projections and height of the coil are measured to see the actual performance of the finished coil.

TEST SHEET

DIAMETER OF THE ROD	:	8 MM
TYPE OF THE STEEL	:	CARBON STEEL (M St.5)
CHARACTERISTIC OF THE μC OUTPUT CURVE	:	CATENARY IN SEGMENTAL FORM
CHARACTERISTIC OF THE COILER SPEED CURVE (REF. FIG. 4.1)	:	CYCLE TIME (T) - 6 sec. INITIAL DELAY (T_1) - 1.5 sec. BACKEND DELAY(T_2) - 1.0 sec. BACKEND DELAY(T_3) - 1.5 sec.
SPEEDS OF THE COILER MOTOR	:	

N_{NOM} = 1035 RPM

N_{MAX} = 1216 RPM

N_{MIN} = 854 RPM

HEIGHT OF THE COIL	:	460 mm
WEIGHT OF THE COIL	:	530 Kg.
REDUCTION IN THE HEIGHT OF THE COIL AS COMPARED TO THE COIL FORMED WITHOUT μC	:	550 mm
CONDITION OF THE END PROJECTIONS	:	NO BACKEND PROJECTIONS
OVERALL PERFORMANCE OF THE COILING	:	VERY GOOD

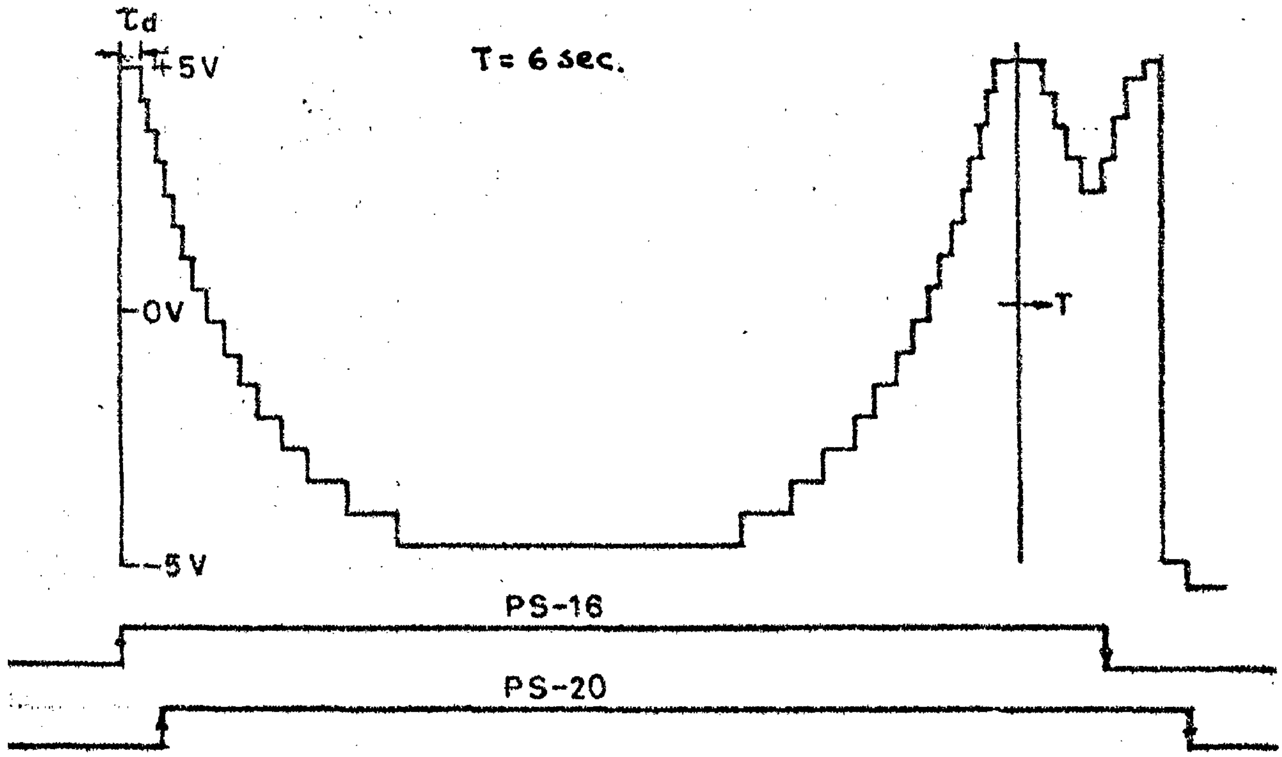

FIG.4.1. MICROCOMPUTER OUTPUT CURVE

CHAPTER - 5

DISCUSSION AND FUTURE SCOPE OF DEVELOPMENT

Using new method for close laying of wire rods, the coil height reduction in the range of 15 - 20 percent has been achieved experimentally. This can solve transportation and storage problem upto a large extent. This improves the quality of storing the finished coils in the yards which ultimately improves the commercial aspect of the product. The end losses due to projections which use to occur invariably in existing system can be reduced very much using new system.

This new coiling method can be implemented in all the four strands (8 coilers). As the coilers in a strand work alternately the same system can be used to drive the other coiler with some modifications. The new system can be utilized to do some extra jobs like counting of coils etc.

The dual converter gives quick response and follows computer output signal faithfully. The motor shaft speed varies smoothly from minimum to maximum speed or vice versa because of moment of inertia though the computer outputs signal changes in steps.

CHAPTER - 6

CONCLUSIONS

With the new system for close laying of wire-rods following points can be concluded :

(i) Programmed speed control of the coiler motor thus the increment of deflecting cone ensured more comp. act laying of coils and reduction in height of the coil 15 to 20 percent.

(ii) A fast response controller for 3 phase dual converter ensures quick acceleration and deceleration of the motor so that the motor follows the reference signal faithfully with minimum time delay and distortion.

(iii) The algorithm takes care of of the back end laying when metal leaves the grip of last rolling stand (thus no more imparting velocity to the metal) through two interrupt subroutines.

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SPECIFICATIONS OF EXISTING DRIVE

(A) MG-Sets

Motor - 3 ϕ squirrel cage Induction Motor
400 V, 160 KW, 1460 rpm

DC Generator - 230 V, 81 KW, 1450 rpm, 353A
Sep. excited, Excitation field resistance 7.32 ohms.

(B) Amplidynes

Induction Motors - 400 V, 8.7 KW, 3000 rpm

Rotary amplifiers- 26A, 230V, 6 KW, 3000 rpm

Excitation by a set of three windings

$OI_1 - OI_2$ - Feed back winding

$OII_1 - CII_2$ - Reference winding

$OIII_1 - OIII_2$ - Stabilized winding

(C) Magnetic Amplifiers

Supply terminals 31, 32

Output terminals 1, 2

Control windings - a set of six windings

$Y_{11} - Y_{12}$ to $Y_{61} - Y_{62}$

(D) Auxiliary Magnetic Amplifier -

$I_{load} = 0.4$ A $R_{load} = 380$ ohms

Supply terminals C_{11}, C_{21}, C_{31}

Output terminals 51, 53

(E) Drive for coilers - DC separately excited

220 V, 26 KW, 113A, 1020 rpm, 100 percent duty cycle

Field separately excited 220 V d.c.

Field current 2.4 A

Field resistance 65 ohms

(F) Tachogenerators

Capacity 0.3 KW, 400 V, 0.65 A, 3000 rpm

Excitation-Separately excited 110 V

Field resistance 375 ohms.

THYRISTOR SYSTEM SPECIFICATIONS
(Supplied by Jyoti Ltd.)

Converter type 3CD06DT, B029

Input

(i) 400 V ± 10 percent, 50 Hz ± 2 percent, 3 wire power supply, 100 AMP capacity.

(ii) 220 ± 10 percent, 50 Hz ± 2 percent, 1 phase aux. supply 15 AMP capacity.

Output

(i) 33V to 330 V dc from 3 phase six pulse converter bridge ± 135A capacity controlled by tacho-generator feedback to regulate speed within ± 0.5 percent. Negative current i.e. braking torque is provided by antiparallel connected regenerative bridge.

(ii) 130 V to 220 V d.c. from single phase full wave, half controlled bridge for field coil.

Current Transformers ACCT1-3 (600/5, 1 percent accuracy 440 V, 15 VA)

Pulse Transformers 2 VT1-14

Synchronising Transformers 120/7-0-7

Power supply transformer 2VT18-19

Sym. Transformer 2 VT 21 (75/7-0-7)

Phase shifting Transformer - 2 VT 22-24

Aux. Transformer	1VT1
Thyristors - 2TH1-2TH6 and 1TH1-1TH6 (46 TB10 with TH42 heat sink)	
Time delay relay	2H3, Pneumatic, RTPN10A1 OFF delay
Phase sequence relay	2H1
Overload relay	2OL1 C.T.operated
Field Loss relay	2H6

APPENDIX – II

LISTING OF MAIN & SUBROUTINE PROGRAMMES

Address		Machine	Code		Level	Instr. Code	Operand	Comment
08	00	31	C0	20	L0	LXI	SP,20E0	
	03	3E	02			MVI	A,02	
	05	D3	20			OUT	20	
	07	3E	8F			MVI	A,8F	
	09	De	03			OUT	03	
	0B	3E	0E			MVI	A,0E	
	0D	30				SIM		
	0E	F3				DI		
	0F	DB	01		L1	IN	01	
	11	07				RLC		
	12	07				RLC		
	13	D2	19	08		JNC	L2	
	16	DA	20	08		JC	L3	
	19	3E	80		L2	MVI	A,80	
	1B	D3	22			OUT	22	
	1D	C3	0F	08		JMP	L1	
	20	3E	80		L3	MVI	A,80	
	22	D3	22			OUT	22	
	24	21	75	28		LXI	H,2875	Initial Delay
	27	4E				MOV	C,M	
	28	C5			L4	PUSH	B	
	29	11	FF	FF		LXI	D,FFFF	
	2C	CD	F1	05		CALL	DELAY	
	2F	C1				POP	B	
	30	0D				DCR	C	

Address		Machine Code			Level	Instr. Code	Operand	Comment
08	31	C2	28	08		JNZ	L4	
	34	CA	37	08		JZ	L5	
	37	21	76	28	L5	LXI	H,2877	Step height
	3A	4E				MOV	C,M	
	3B	21	77	28	RPT	LXI	H,2877	Maximum +ve voltage
	3E	7E				MOV	A,M	
	3F	D3	22			OUT	22	
	41	F5				PUSH	PSW	
	42	21	8F	28		LXI	H,288F	Look up table
	45	CD	6C	08		CALL	SYNC	
	48	F1				POP	PSW	
	49	81			L6	ADD	C	
	4A	D3	22			OUT	22	
	4C	F5				PUSH	PSW	
	4D	CD	6C	08		CALL	SYNC	
	50	F1				POP	PSW	
	51	C3	00	20		LXI	H,2878	
	54	00				CMP	M	
	55	DA	49	08		JC	L6	
	58	CA	5B	08		JZ	L7	
	5B	91			L7	SUB	C	
	5C	D3	22			OUT	22	
	5E	F5				PUSH	PSW	

ddress		Machine Code			Level	Instr. code	Operand	Comment
3	5F	CD	6C	08		CALL	SYNC	
	62	C3	99	09		JMP	09.99	
	65	00				NOP		
	66	CA	A3	09		JZ	RPT1	
	69	D2	5B	08		JNC	L7	
8	6C		SYNC	SUBROUTINE				
8	6C	23			SYNC	INX	H	
	6D	5E				MOV	E,M	
	6E	23				INX	H	
	6F	56				MOV	D,M	
	70	DB	D1		L1	IN	01	
	72	07				RLC		
	73	07				RLC		
	74	07				RLC		
	75	D2	70	08		JNC	L1	
	78	DA	7B	08		JC	L2	
	7B	DB	01		L2	IN	01	
	7D	07				RLC		
	7E	07				RLC		
	7F	07				RLC		
	80	DA	7B	08		JC	L2	
	83	D2	86	08		JNC	L3	
	86	06	0C		L3	MVI	B,0C	

ddress	Machine Code			Level	Instr. code	Operand	Comment
8 88	05			L4	DCR	B	
89	C2	88	08		JNZ	L4	
8C	1B				DCX	D	
8D	7A				MOV	A,D	
8E	B3				ORA	E	
8F	C2	70	08		JNZ	L1	
) 92	C8				RZ		
20 C8	C3	93	08	JMP	RST6.5	Back and subroutine	
08 93	C3	AA	09		JMP	09AA	
96	21	79	28		LXI	H,2879	
99	7E				MOV	A,M	
9A	D3	22			OUT	22	
9C	:5				PUSH	PSW	
9D	23				INX	H	
9E	4E				MOV	C,M	
9F	C5			L1	PUSH	B	
A0	11	FF	01		LXI	D,01FF	
A3	CD	F1	05		CALL	DELAY	
A6	C1				POP	B	
A7	0D				DCR	C	
A8	C2	9F	08		JNZ	L1	
AB	CA	AE	08		JZ	L2	
AE	F1			L2	POP	PSW	

ddress	Machine Code			Level	Instr. Code	Operand	Comment
8 AF	23			L3	INX	H	
B0	4E				MOV	C,M	
B1	B9				CMP	C	
B2	D2	BB	08		JNC	L4	
B5	CA	DB	08		JZ	L7	
B8	DA	DB	08		JC	L7	
BB	23			L4	INX	H	
BC	4E				MOV	C,M	
BD	91				SUB	C	
BE	D3	22			OUT	22	
C0	F5				PUSH	PSW	
C1	23				INX	H	
C2	4E				MOV	C,M	
C3	C5			L5	PUSH	B	
C4	11	FF	01		LXI	D,01FF	
C7	CD	F1	05		CALL	DELAY	
CA	C1				POP	B	
CB	0D	00	00		DCR	C	
CE	C2	C3	08		JNZ	L5	
D1	CA	D4	08		JZ	L6	
D4	F1			L6	POP	PSW	
D5	21	7A	28		LXI	H,287A	
D8	C3	AF	08		JMP	L3	
DB	D3	22		L7	OUT	22	
DD	F5				PUSH	PSW	

label

Address		Machine Code			Level	Instr. code	Operand	Comment
08	DE	21	7E	28		LXI	H,287E	
	E1	4E				MOV	C,M	
	E2	C5			L8	PUSH	B	
	E3	11	FF	02		LXI	D,02FF	
	E6	CD	F1	05		CALL	DELAY	
	E9	C1				POP	B	
	EA	0D				DCR	C	
	EB	C2	E2	08		JNZ	L8	
	EE	3E	80			MVI	A,80	
	F0	D3	22			OUT	22	
	F2	23				INX	H	
	F3	4E				MOV	C,M	
	F4	C5			L9	PUSH	B	
	F5	11	FF	02		LXI	D,02FF	
	F8	CD	F1	05		CALL	DELAY	
	FB	C1				POP	B	
	FC	0D				DCR	C	
	FD	C2	F4	08		JNZ	L9	
09	00	CA	03	09		JZ	L10	
	03	3E	0A		L10	MVI	A,0A	
	05	30				S1M		
	06	FB				E1		
	07	C3	00	08		JMP	L0	

ddress	Machine	Code		Level	Instr. code	Operand	Comment
0 CE	C3	0A	09	JMP	RSI 7.5		Back end subroutine
9 0A	C3	B1	09		JMP	09,B1	
0D	21	80	28		LXI	H,2880	
10	7E				MOV	A,M	
11	D3	22			OUT	22	
13	F5				PUSH	PSW	
14	23				INX	H	
15	4E				MOV	C,M	
16	C5			L1	PUSH	B	
17	11	FF	01		LXI	D,01FF	
1A	CD	F1	05		CALL	DELAY	
1D	C1				POP	B	
1E	0D				DCR	C	
1F	C2	16	09		JNZ	L1	
22	CA	25	09		JZ	L2	
25	F1			L2	POP	PSW	
26	23			L3	INX	H	
27	4E				MOV	C,M	
28	B9				CMP	C	
29	DA	32	09		JC	L4	
2C	CA	50	09		JZ	L7	
2F	D2	50	09		JNC	L7	
32	23			L4	INX	H	
33	4E				MOV	C,M	

Address		Machine Code			Level	Instr. code	Operand	Comment
09	34	81				ADD	C	
	35	D3	22			OUT	22	
	37	F5				PUSH	PSW	
	38	23				INX	H	
	39	4E				MOV	C,M	
	3A	C5			L5	PUSH	B	
	3B	11	FF	01		LXI	D,01FF	
	3E	CD	F1	05		CALL	DELAY	
	41	C1				POP	B	
	42	0D				DCR	C	
	43	C2	3A	09		JNZ	L5	
	46	CA	49	09		JZ	L6	
	49	F1			L6	POP	PSW	
	4A	21	81	28		LXI	H,2881	
	4D	C3	26	09		JMP	L3	
	50	D3	22		L7	OUT	22	
	52	F5				PUSH	PSW	
	53	21	85	28		LXI	H,2885	
	56	4E				MOV	C,M	
	57	C5			L8	PUSH	B	
	58	11	FF	02		LXI	D,02FF	
	5B	CD	F1	05		CALL	DELAY	
	5E	C1				POP	B	
	5F	0D				DCR	C	

Address		Machine	Code		Level	Instr. code	Operand	Comment
09	60	C2	57	09		JNZ	L8	
	63	3E	80			MVI	A,80	
	65	D3	22			OUT	22	
	67	23				INX	H	
	68	4E				MOV	C,M	
	69	C5			L9	PUSH	B	
	6A	11	FF	02		LXI	D,02FF	
	6D	CD	F1	05		CALL	DELAY	
	70	C1				POP	B	
	71	0D				DCR	C	
	72	C2	69	09		JNZ	L9	
	75	CA	00	08		JZ	L0	