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APPLICATION OF THYRISTORS IN ROLLING MILLS

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I. INTRODUCTION

Since thyristors were first developed about 10 years ago, their range of application has widened remarkably. One of the most outstanding examples has been their use in rolling mills. In recent rolling mills, thyristors are almost always used in the variable voltage dc source for the main and auxiliary drive dc motors. The M-G converters are used only in cases where there are special limitations on power source. Although the major reasons for this rapid development of thyristor applications are the remarkable progress on thyristor manufacturing techniques, the establishment of protective systems and the realization of control techniques, other important factors are the large equipment investments and desire for more rational equipment in the steel industry, as well as the continuous search for new techniques by which higher quality products can be produced more economically.

The main applications of thyristors in rolling mills are as follows:

1) Static Leonard control of dc motors

As thyristors are made to withstand higher voltages and currents, they can be used in main drive dc motors having capacity of several thousand kw. It is also thought that pressure contact thyristors are most suitable for frequently repeated intermittent loads like those of rolling mills.

2) Variable speed control of ac motors

By using variable frequency and variable voltage inverters in ac motor power sources, highly accurate variable speed operation is possible. And this application will certainly increase gradually as time goes on.

3) Contactless ac switches

Thyristors are often used for operation of magnetic valves since they are ideal for high frequency of switching.

Fuji Electric has delivered many thyristor Leonard systems for use in various types of processing lines, tube mills, wire rod rolling mills, cold rolling mills, hot strip mills and hot reversing mills. The example given in this article is thyristor Leonard equipment for a 11,200 kw blooming mill which was delivered to the Fukuyama Works of Nippon Kokan K.K. in February 1969.

Table 1 gives the ratings of the main drive.

The main motors consist of two 5600 kw double armature dc motors. The shear motors are also two 1850 kw double armature dc motors. Thyristor Leonard power sources are employed as the dc sources for these main drive and shear drive motors as well as the auxiliary drive variable voltage dc motor (total output: about 24 Mw).

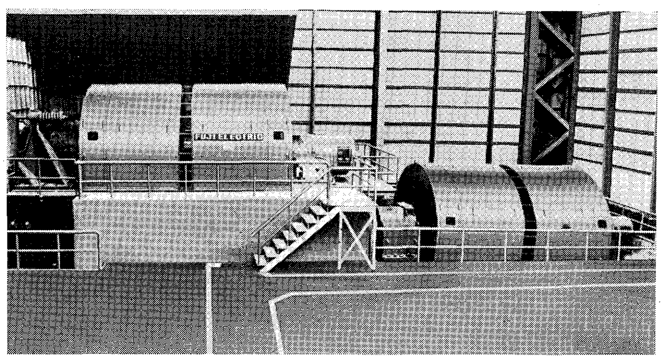

Fig. 1 Dc motors for main rolls

Table 1 **Ratings of Main Motors and Converters**

	Motor				Converter Equipment				
	No.	Voltage	Rating	Construction	No.	Voltage	Rating	Connection	Phase No. of converter connection
Main Drive	2	750 v	2×2800 kw	Double armature	4	750 v	3110 kw	3ϕ bridge cross-connection (symetrical)	12-phases in 2 groups of converters
Shear Drive	2	750 v	2×925 kw		2	750 v	1970 kw	3ϕ bridge closs-connection (asymetrical)	
Aux. Drive	Overall capacity about 24,200 kw				Overall capacity about 29,000 kw			3ϕ bridge closs and anti-parallel connection	—

When large capacity thyristor Leonard systems are used, it is essential to investigate thoroughly the disturbances caused in the ac source by source voltage variations, distortion of voltage wave form, large reactive power requirement, generation of harmonic currents etc. This equipment was designed and manufactured after thorough investigations into all of these problems.

II. THYRISTOR CONVERTERS

1. Thyristors and Thyristor units

The thyristors used in this equipment were 2500 v 400 amp flat-packaged-types (forced-air cooling) for the main and shear drive motors and 800 v～1600 v 200 amp stud-types (forced-air cooling) for the auxiliary driver. Both of these types of thyristors employ the pressure contact type developed by Fuji Electric. Their main feature of these thyristors is that there is no thermal fatigue with intermittent loads which are frequently repeated.

All of these thyristors are compactly installed in drawout-type units (thyristor units) which also include cooling fins, rapid fuses with warning equipment, a gate pulse transmission circuit and an R-C filter. The R-C filter is intended to suppress the thyristor commutation stress, which is especially important in thyristors with high current and high voltage. The fuse " blow-out " warning circuit detects also any abnormalities in the R-C filter. The gate pulse transmission circuit is designed to superpose a tall narrow pulse with a low wide-band pulses in order to minimize turn-on loss, and prevent fiiring loss, as well as guarantee the firing of several thristors connected in parallel.

2. Thyristor Cubicle

The thyristor cubicle contains the thyristors and cooling fan. The cooling air is injected from the bottom and ejected from the top of the cubicle via a sound-proof duct. *Fig. 2* shows the arrangement of thyristors in converter cubicle (one for each of the armatures of the main motors). The cubicle contains 3-phase bridge forward and reverse converters and six ac current transformers. However, since the current does not flow in both converter simultaneously, the cooling effect can be improved, for example, by arranging the forward converter in the upper part and the reverse converter in the lower part. Since the thyristors are connected in parallel, the best results can be obtained by arranging the conductors so that generated loss and the transient current load are balanced. The standand force-cooled thyristor cubicles can contain 18 thyristors of the flat-packaged type and 36 thyristors of the stud-type. *Figs. 3* and *4* show an external and internal view of the flat-packaged type thyristor cubicle.

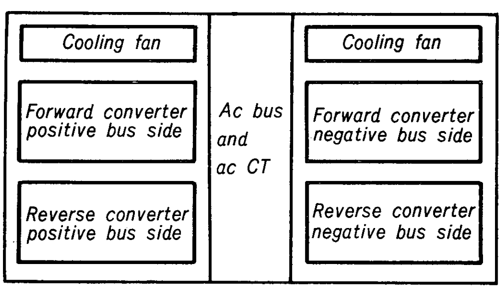

Fig. 2 Arrangement of thyristors in the cubicle

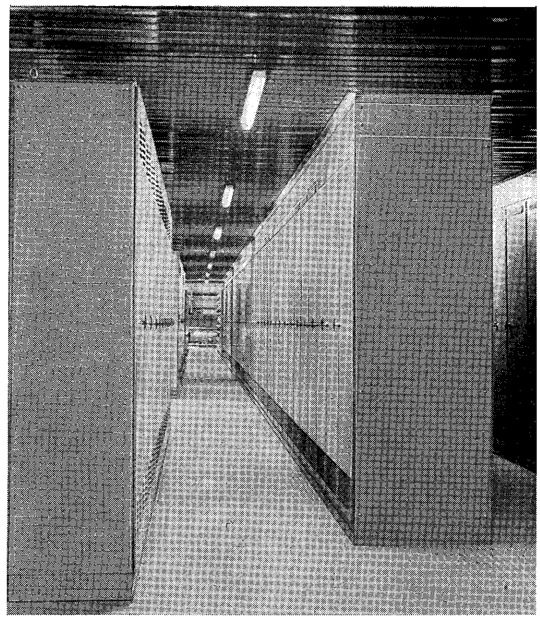

Fig. 3 Thyristor cubicle

3. Thyristor Protection

Since the thyristors are used at an operating voltage near the permissible voltage and the thermal time constant is low as compared with those of ordinary electrical equipment, the most important thing is to select the best protection system for using thyristors upon the rolling mill.

1) Overvoltage protection

Thyristors have the lowest voltage withstand in all the circuits, but it is possible in principle to make the voltage safety factor of the thyristors equal to the circuit withstand voltage so that there will be no partial breakdowns. However, it is not practical to take a safety factor which is equal to the withstand voltages appropriate for usual electrical equipment.

The voltage safety factor is usually selected between 2.0 and 2.5. Appropriate surge overvoltage protection equipment is provided for higher surge voltage which exceed the safety factor. The surge voltage include abnormal voltages arising because of lightning surges from the nets, switching surges when the circuit breaker on the primary side of thyristor transformer is closed and is opened under no load conditions. Arrestors and R-C filters are provided on the secondary side of the transformer to deal with these over-

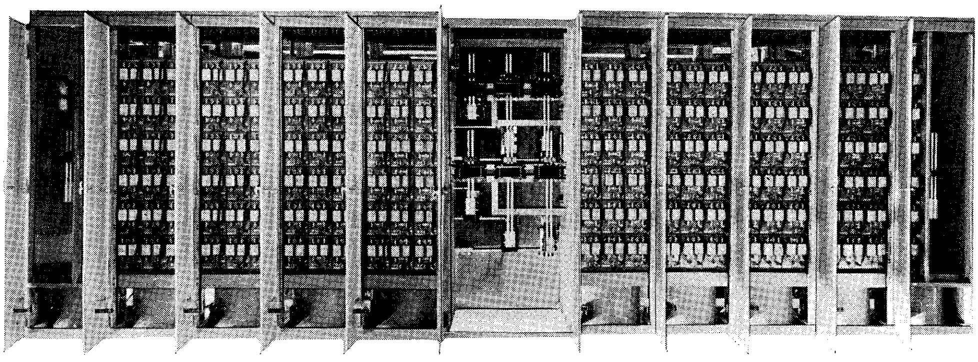

Fig. 4 Internal view of thyristor cubicle

voltages in the converters for main drive. In previous arresters, the limit voltage was high and they were not suitable for thyristor protection, but a new type of arrestor has been developed for this equipment with a limit voltage lower than the permissible thyristor voltage. The R-C filter employs a system to prevent capacitor discharge current flow to the thyristor so as to minimize thyristor turn-on loss. This filter can lessen the surge voltage rise rate dv/dt and also attenuate the voltage peak by absorbing the surge energy. The arrester serves as a back up for the filter.

2) Overcurrent protection

The control equipment performs current limit control and gate puls shifting for overcurrent protection. The rapid fuse equipped with each thyristor serves to eliminate the faulty thyristor quickly whenever there is an internal fault in the converter (element breakdown, erroneous firing) so as to prevent the fault from spreading to the undamaged elements. A major problem, especially in large capacity equipment, is maintenance when large numbers of fuses are blown by overcurrents caused by short-circuits of dc bus bar, flashover of the motor or commutation failure in the converter. To solve this problem, this equipment contains a high speed circuit breaker which is designed with the help of dc reactors so that the fuses will not be blown between the time the accident arises and interruption is completed. The effectiveness of this method has been confirmed in tests. The arc voltage which occurs during operation of the high speed breaker threatens the withstand of the thyristors and motor, but high stability is insured by carefully considering the inductance distribution.

III. CONTROL EQUIPMENT

All of the controllers is transistorized to obtain high operating efficiency as well as excellent control characteristics. The new TRANSIDYN system used in this equipment exhibits very high reliability in respect to temperature and voltage variations. In previous logic circuits combined with transistorized controller, several magnetic relays with contacts were employed but this equipment contains only the Fuji Electric standard F-MATIC logic elements which are completely contactless and insure high operating reliability. Analog and logic signals are mixed in the control circuits of motors and in order to keep the the operating reliability high and the response rapid, the voltage, current and motor speed detecter consist of specially manufactured rapid-response equipment with no noise or ripple. All of the various types of controllers and operators are included in units, each with a single function, and when required, suitable standard units can be combined. Even with complex control equipment, the use of such unit components leads to improved equipment reliability and also greatly facilitates maintenance. *Fig. 5* shows a TRANSIDYN control unit.

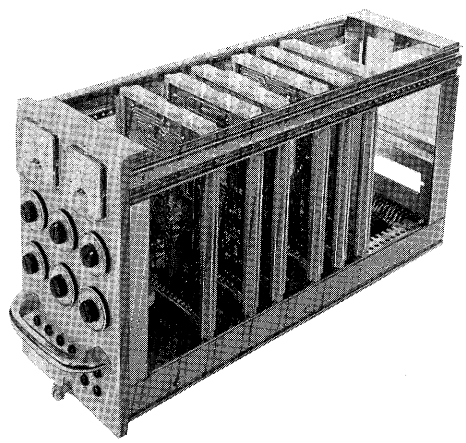

Fig. 5 TRANSIDYN control unit

1. Main Drive Motor Control Circuit

Fig 6. is a block diagram of the main drive motor control circuitry. The control loop contains separate speed controllers for the upper and lower motors and within the speed control loop, there is an armature current minor loop for each of the armatures. The speed reference from the master controller is led to acceleration operator (HLR) via a non-linear operator so as to convert from notch to speed reference. In the HLR, the step signal is converted into a speed reference voltage with a constant gradient. In the

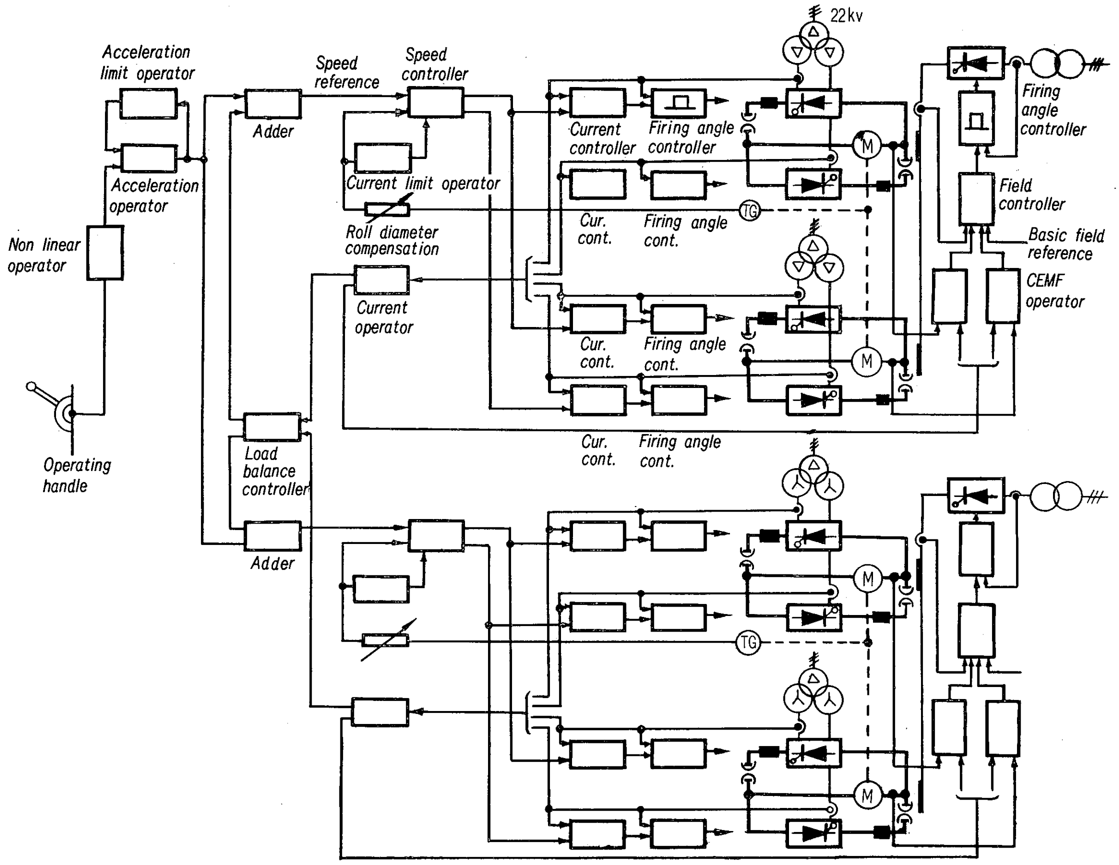

Fig. 6 Main motor control system block diagram

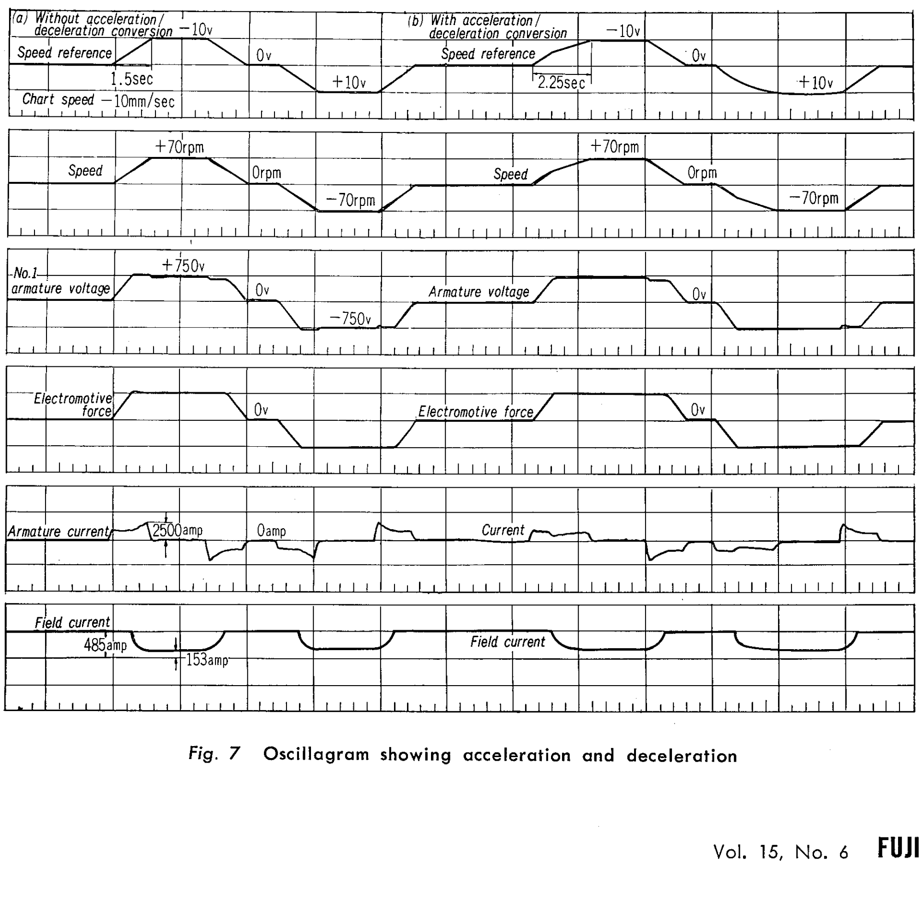

Fig. 7 Oscillagram showing acceleration and deceleration

HLR, it is also possible to select a constant ratio of the change of speed between minus top and plus top speed or select automatic conversion of the ratio beween zero to base speed and base speed to top speed. The HLR output is led to speed controllers (ASR) for the upper and lower motors. The load balance compensation signal for the upper and lower motors is added to the ASR input. Since the ASR output becomes the reference signal for the subsequent armature current control loop, this output is limited to a value which agrees with the working maximum current of the main roll motor. This value is processed by the current limit operator as a function of the motor speed. When the ASR is saturated and current limit control of the main motor is under way, the speed control system ceases to function and the main roll speed is not controlled. In order to avoid this condition as much as possible, saturation of the speed controller is detected, and this signal is fed to the ASR input and fed back to the HLR so that the speed reference is reduced. In this way saturation of the speed control loop is relieved.

In the field control system, the field current control loop maintains the full field current when the counter electromotive force is equal to or belew the rated value. When the counter electromotive force exceeds the rated value, there is automatic switching to the counter electromotive force control loop by which the field can be automatically weakened. *Fig. 7* shows oscillograms obtained during acceleration and deceleration of the main drive motor.

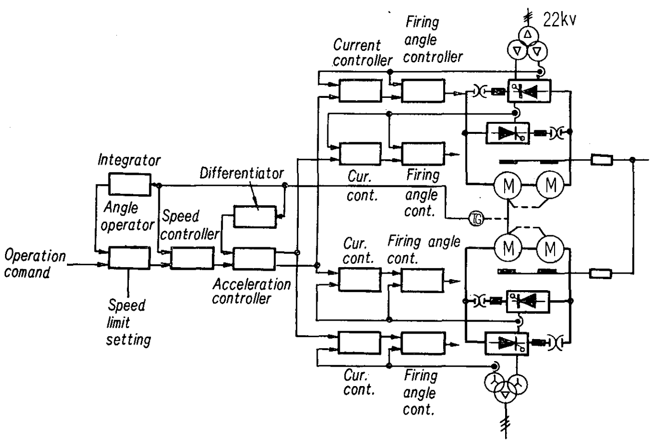

Fig. 8 Shear motor control system block diagram

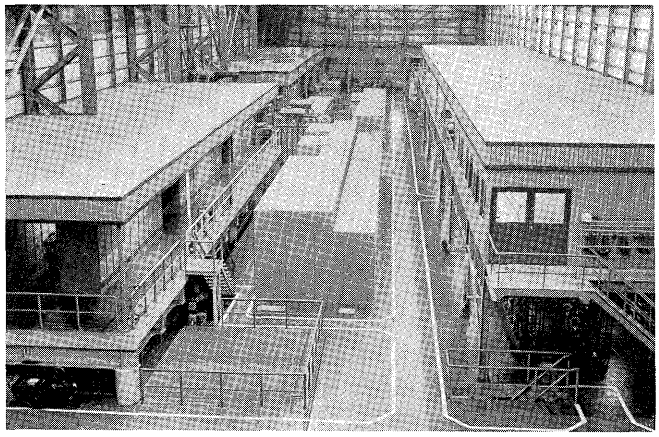

Fig. 9 Electrical room

2. Shear Drive Motor Control Circuit

Fig. 8 is a block diagram of the shear drive motor control circuit. When a shear command is given, 1-cycle operation is required which means that the shear crank shaft is turned through one revolution, returned to the point of origin again and automatically stopped. In order to perform this 1-cycle operation effectively, an angle operator is provided. The relation between the angle $\Delta\theta$ through which the shear crank must be turned from some arbitrary time point back to the point of origin, and the speed ω which must exist at this time point to provide constant deceleration, is $\Delta\theta=\omega^2$. The angle operator obtains $\Delta\theta$ through the actual rotation angle by integrating the output of the tachogenerator and the rotating angle reference, and then calculate ω from $\Delta\theta$. The output of the angle operator becomes the speed reference for the subsequent speed control loop.

The shear cutting speed is stipulated according to the output limit value of the angle operator. Since the speed controller provides the reference signal for the subsequent acceleration control loop, the speed controllor output is limited in accordance with the acceleration required for the shear operating cycle. This is intended to avoid unnecessary large increases in root mean square value of the armature current which is caused from rapid acceleration or deceleration. The acceleration controller limits this acceleration value in a suitable value and also suppresses overshooting of the motor speed after completion of shearing.