Use of Steam Turbines as Mechanical Drives with a View to Improve the Techno—Economic Efficiency in Paper Mills Working

Mr. J. C. Mahanti & Mr. T. N. Chaturvedi
The Titaghur Paper Mills Company Limited.

In the present study the concept of utilising steam turbines for mechanical drives has been elaborated primarily with a view to improve the techno-economic efficiency of the pulp and paper mills. While some of the paper mills are already using the steam turbines for various mechanical drive applications, it is felt necessary to again emphasize the importance of this concept with a view to achieve substantial reduction in energy cost, as well as to meet the present shortage of electrical energy.

The steam turbine is a prime mover in which the potential energy of the steam is transformed into kinetic energy and the latter, in its turn, is transformed into the mechanical energy of rotation of the turbine shaft. The Turbine shaft can be connected to the driven equipment either directly or through a reduction gearing depending upon the speed requirement of the driven equipment. This prime mover is considered specially suitable for the process industries like pulp and paper, where large amount of energy is required at comparatively lower potential for process heating. Thus, if the steam at higher potential energy is reduced to a lower potential in the turbine for making it suitable for the process heating purpose and the energy difference is utilised as useful mechanical work by driving process equipment, the mechanical energy is available more-or-less as a by-product. The whole process is in accordance with the total energy concept where the thermal efficiency approaches unity.

However, due to large energy requirement for process heating purpose, almost all the paper mills are already using Back-Pressure. Type or extraction-condensing type Turbo-generator sets for in-plant electrical power generation, where either full or major part of the steam is extracted at lower potential energy for process requirements and balance quantity, if any, is further expanded till condensed. Thus, a part of the power generation by the Turbo-set is due to reduction in the pressure and temperature of the steam; the balance power being generated by the portion of the condensing steam flow.

Although expanding the steam in a single multistage Turbine results in considerably more power generation for any particular requirement of L.P. Steam, direct drive of equipment by steam Turbine has several advantages.

When the electrical energy, generated or purchased, is used for the mechanical drive purpose, it has to be transmitted through costly electrical distribution system including transformer and switchgears besides the starting gear and the electrical motor which drives the equipment. Right from the Alternator of the turbine, through the transformer, switchgear, cables, starter and motor, energy is continuously lost. On the other hand, in case of mechanical drive by means of the steam turbine, the loss of energy is negligible and the problems of power generation and distribution are not to be faced.

The steam Turbines suitable for the mechanical drive applications in paper mills are of Back-Pressure design taking steam at high or medium pressures and temperatures and exhausting at lower pressures around 30-40 psig. At least two indigenous manufacturers are manufacturing these turbines, which are mostly being used in the sugar industry. The speeds of these turbines are around 3000-6000 RPM and for most mechanical drive applications it is essential to use a reduction gear to reduce the speed to the desired value. These turbines are mostly single-stage turbines with comparatively low efficiency viz: 50-55% which results in exhaust steam being superheated. To utilies this exhaust steam for process heating, it requires to be desuperheated and for this purpose a desuperheater is installed in the exhaust steam line. The steam rates i.e. quantity of steam required per KWH power are also high. Since the exhaust steam is completely utilised in process heating, the lower efficiency of the turbines does not result in any appreciable loss of energy. Only the steam requirement per unit power output is high and careful steam balancing is necessary while considering the use of these turbines. However, the manufacturers offer to supply turbines with two or more stages with consequent higher efficiencies of the order of 65-70% and lower steam rates, but the prices of these turbines are almost double that of the single stage turbines. The single multi-stage turbines are being extensively used for drives of Boiler Feed Pumps, Fans, Blowers etc. Figure I shows the schematic diagram for use of the back-pressure steam turbine in mechanical drive with process heating applications.

We have attempted to carry out a detailed analysis in computing the operational cost of the steam turbine drive and compare these costs with the operational cost of a electric motor drive system. The steam turbine system has been considered complete with the inlet and outlet pipelines together with the desuperheater. The electric motor considered are slip-ring induction motors. Upto 300 HP drives, operation on 415 volts power distribution system has been considered and for higher rated drives the motors operated on 6.6 KV distribution have been considered. It has been assumed that the 415 volts electric power distribution system has adequate Transformer and switchgear capacity and only installation of fuse switch units with automatic starting gear, cables, power capacitors and the electric motor have been taken into account.

TABLE I — **Electric Motor Drive**
Motors used are Slipring Induction Motors

Drive rating (H.P.)	*Sytem voltage (Volts)*	*Switch fuse unit rating (Amps)*	*Starter*	*P.V.C. cable size (core × mm2)*	*Power capacitor rating (Kvar)*
100	415	200	170	3×150	20
200	415	400	300	3×400	40
300	415	600	400	2×3×240	60
400	6600	—	630*	3×35	80
500	6600	—	630	3×50	100
600	6600	—	630	3×70	120
700	6600	—	630	3×95	140
800	6600	—	630	3×95	160
900	6600	—	630	3×120	180
1000	6600	—	630	3×120	200

*For 6.6 KV starting of motors, DOL starting by H.T. Breaker and relay has been considered. Cable length of 150 metres has been considered.

For 6.6 KV system DOL starting has been considered and provision has been made only for circuit breaker with relay, cable, power capacitor and the electric motor. Figure 2 shows the details of these systems.

Discussions were held with the technical representatives of the manufacturers to obtain reasonable budgetary estimates for the various equipment and the total installed costs as well as the operational costs have been computed as per the details shown in the Tables I, II, III & IV of the Annexure I.

TABLE II

Steam Turbine Drive

Intet steam at 18.3 kg/cm²g pressure 343°C, Exhaust steam at 2.1 kg/cm²g pressure.

Steam flow kg/hr.	*Pipe line size, inch NB* *H.P. Steam inlet IBR*	*L.P. Steam exhaust non-IBR*
1,590	2½	4
3,180	3	6
4,770	4	6
6,360	4	6
7,950	4	8
9,540	5	8
11,140	5	8
12,730	6	8
14,320	6	8
15,910	6	10

Steam Turbines considered are all single stage, back pressure steam turbines with efficiency around 50-55%. Desuperheater is complete with temperature transmitter, indicator and controller. Pipe line lengths considered are approx 150 ft each on HP & LP side.

TABLE III

Installed and Operation Costs of Steam Turbine

Drive Rating H.P.	Cost of Turbine & Gear (Rs.) A	Cost of Desuperheating station (Rs.) B	Pipe line costs (Rs.) C	Total cost (Rs.) D	Spares & Installation cost @ 10% of D (Rs.) E	Total Istalled cost (Rs.) F=D+E	Maint. Cost per year @ 5% of F (Rs.) G	Interest on capital @ 15% per year (Rs.) H
100	1,00,000	23,000	23,000	1,46,000	14,600	1,60,600	8,030	24,090
200	3,00,000	25,000	29,000	3,54,000	35,400	3,89,400	19,470	58,410
300	3,00,000	27,000	33,000	3,60,000	36,000	3,96,C00	19,800	59,400
400	4,00,000	32,000	33,000	4,65,000	46,500	5,11,500	25,575	76,725
500	4,00,000	37,000	49,000	4,86,000	48,600	5,34,600	36,730	80,190
600	4,00,000	47,000	53,000	5,00,000	50,500	5,50,000	27,500	82,500
700	4,00,000	57,000	53,003	5,10,000	51,000	5,61,000	28,050	84,150
800	4,03,000	77,000	55,000	5,32,000	53,200	5,85,200	29,260	87,780
900	4,00,000	92,000	55,000	5,47,000	54,700	6,01,700	30,085	90,255
1000	4,00,000	1,00,000	63,000	5,63,000	56,300	6,19,300	30,965	92,895

Total heat available = 750 — 133.5 = 616.5 Mcal/Tonne
Heat utilised in Turbine = 750 — 652 = 98 Mcal/Tonne
i.e 15.89% of Total energy available is utilised in Turbine (say 16%)
Steam cost at 18.3 kg/cm^{2}g & 343°C = Rs. 22.00 per tonnes (assumed)
Steam cost allocated to turbine = 16% of 22/- = Rs. 3.50 per tonne

TABLE III (Contd.)

Drive Rating (HP)	Steam cost per year (Rs.) I	Total operational cost per year (Rs.) J	Operational cost per day (Rs.) K
100	44,075	76,195	231
200	88,150	1,66,030	503
300	1,32,225	2,11,425	641
400	1,76,300	2,78,600	844
500	2,20,375	3,27,295	992
600	2,64,450	3,74,450	1135
700	3,08,800	4,21,000	1276
800	3,52,875	4,69,915	1424
900	3,96,950	5,17,290	1568
1000	4,41,025	5,64,885	1712

The operation of turbine is assumed to be for 24 hours a day for 330 days in a year.

The operational costs for both the steam turbine driven system and electric motor driven system have been plotted in Figure 3, for the drives of different Horse-power ratings ranging from 100 HP upto 1000 HP. A study of the graph reveals that the operating costs of the electric motor drive are approximately three times than that of the steam turbine drive. For example, taking the case of an 800 HP rated drive, the yearly operational cost for steam turbine drive is approx. Rs. 4,69,915/- as compared to the operational cost of the electric motor drive, which is approx. Rs. 13,82,864/-. The use of steam turbine drive for this application will result in an

TABLE IV

Installed and operation cost of Electric Motor drive

Drive rating (HP)	*Cost of motor* (*Rs.*) *A*	*Cost of starting gear and switch* (*Rs*) *B*	*Cost of Cable* (*Rs.*) *C*	*Cost of Power capacitor* (*Rs.*) *D*	*Total cost* (*Rs.*) *E*	*Spares and Installation @ 15% of (E)* (*Rs.*) *F*	*Total Installed cost* (*Rs*) *G*	*Maint. cost @ 5% of (G) per year* (*Rs.*) *H*	*Inerest on capital @ 15% of (G) per year* (*Rs.*) *I*
100	28,000	37,000	9,000	3,000	77,000	11,550	88,550	4,428	13,284
200	57,000	52,000	24,000	6,000	1,39,000	20,850	1,59,850	7,993	23,979
300	95,000	72,000	31,000	9,000	2,07,000	31,050	2,38,050	11,903	35,709
400	1,80,000	50,000	6,000	12,000	2,48,000	37,200	2,85,200	14,260	42,780
500	2,10,000	50,000	8,000	15,000	2,83,000	42,450	3,25,450	16,273	48,819
600	2,30,000	50,000	10,000	18,000	3,08,000	46,200	3,54,200	17,710	53,130
700	2,50,000	50,000	12,000	21,000	3,33,000	49,950	3,82,950	19,148	57,444
800	2,75,000	50,000	12,000	24,000	3,61,000	54,150	4,15,150	20,758	62,274
900	3,00,000	50,000	13,000	27,000	3,90,000	58,500	4,48,500	22,425	67,275
1000	3,50,000	50,000	13,000	30,000	4,43,000	66,450	5,09,450	25,473	76,419

Assumed Power cost @ Rs. 0.25 per KWH and 10% losses.

TABLE IV (Contd.)

Drive rating (HP)	*Power cost per year* (*Rs.*) *J*	*Total Operational cost per year* (*Rs.*) *K*	*Total operational cost per day* (*Rs.*) *L*
100	1,62,479	1,80,191	546
200	3,24,958	3,56,930	1,082
300	4,87,437	5,35,049	1,621
400	6,49,916	7,06,956	2,142
500	8,12,395	8,77,487	2,659
600	9,74,874	10,45,714	3,169
700	11,37,353	12,13,945	3,679
800	12,99,832	13,82,864	4,190
900	14,62,311	15,52,011	4,703
1000	16,24,790	17,26,682	5,232

annual saving, in the operational costs, of approx. Rs. 9.13. lacs. The capital investment in the steam turbine drive is paid back in about 6/7 months time only. Hence, it is clear that utilisation of steam turbines for mechanical drive application is likely to result in substantial improvement in the techno-economic efficiency of the mill.

The paper industry is capital intensive and large amount of capital investment is required for installation of new paper production capacity. The present day costs work out to approx. Rs. 30 to 40 lacs for each metric tonne/day of new paper production capacity. However, it has been found much more economical to increase the production capacity of the existing paper mills particularly the old units by ensuring maximum capacity utilisation. This involves suitable additions and alterations to the various sections of the mill and a well thought-out paper machine rebuilding programme. While achieving the increased production by the balancing of the old mills, it is usually not possible to increase the electric power generation by installation of additional Turbo-Generator set due to the very high capital requirement and prolonged delivery. Moreover, sometimes the marginal increased Power requirement, say below 1000 KW does not justify the installation of a new Turbo-Generator set. Further, the requirement of L. P. process steam also goes up with the increase in production, and it may not be possible to increase the L. P. steam extraction from the Turbo-Generator set. Under such circumstances, the additional energy requirement can be most efficiently and quickly met by going in for steam turbine drive for some of the equipment requiring high Power input, like Paper Machines, Fans, Blowers, Pumps etc. This is particularly relevant in today's electric power shortage in the country, and additional power for increased production is not at all available. As a matter of fact, in many cases the production capacity is underutilised due to non-availability of adequate electric power. The use of desuperheated exhaust steam of the drive turbines will result in the requirement of lesser quantity of low-pressure steam extraction from the main Turbo-Generator sets and at least a part of this reduction in LP steam extraction can be diverted to increase the condensing portion of the turboset steam flow. This will result in increased amount of power generation from the Turboset.

To illustrate this point, consider the case of a 5 MW extraction-condensing Turbo-alternator set as shown in Figure 4. Suppose a back-pressure steam turbine, with desuperheater in the exhaust steam line, is utilised to drive an equipment, say an Induced/Forced draft fan requiring approx. 250 KW Power. The exhaust of this turbine at 2.1 kg/cm^2g pressure, after desuperheating, is fed back to the main low pressure process steam header. The steam rate for this single stage turbine is estimated to be around 16.4 tonnes per KWH. The turbine will therefore, require steam, at 18.3 kg/cm^2g pressure and 343°C temperature, at a flow rate of approx. 4100 kg/hr and exhaust this quantity of steam fin the LP steam header at 2.1 kg/cm^2g pressure. The extraction of LP steam required from the main Turboset is now less by approx. 4 tonnes/hr. If the total quantity of steam passed through the main turboset is kept same by passing 4 tonnes/hr more steam to the condenser, the new LP steam extraction and condensing steam flow will now be 30 tonnes/hr and 12 tonnes/hr respectively instead of the original figures of 34 tonnes/hr and 8 tonnes/hr. The new amount of power generated will now be 4.186 MVA in place of the original figure of 4 MVA. This shows an increase in power generation by approx. 4.6%, besides 250 KW reduction in the total electric power demand on account of the ID/FD Fan. This increased amount of power now available can be used for increasing the production capacity. In Paper mills the steam turbine drives are suggested for the following applications :-

1. Paper Machine Drive
2. Drives for Blowers and Pumps
3. Boiler Feed Pump Drives
4. Boiler I. D. and F. D. Fan Drives

The steam turbine drive for Paper Machines is of particular significance to "Mini Paper Plants" below 30 tonnes/day production. These units do not have any inplant power generation due to the very high capital investment involved. The requirement of power for drive of Paper M/c is about 10 HP/MTD i.e. a 20 TPD Paper Machine will require a 200 HP drive. If a Turbine is installed for the drive of the Paper Machine the exhaust steam available would be about 2.5 tonnes/hr which is just adequate for drying the Paper. This would, of course, mean higher investment in the Boiler for producing superheated medium pressure steam, which will be compensated by the considerably lower energy costs, as explained earlier.

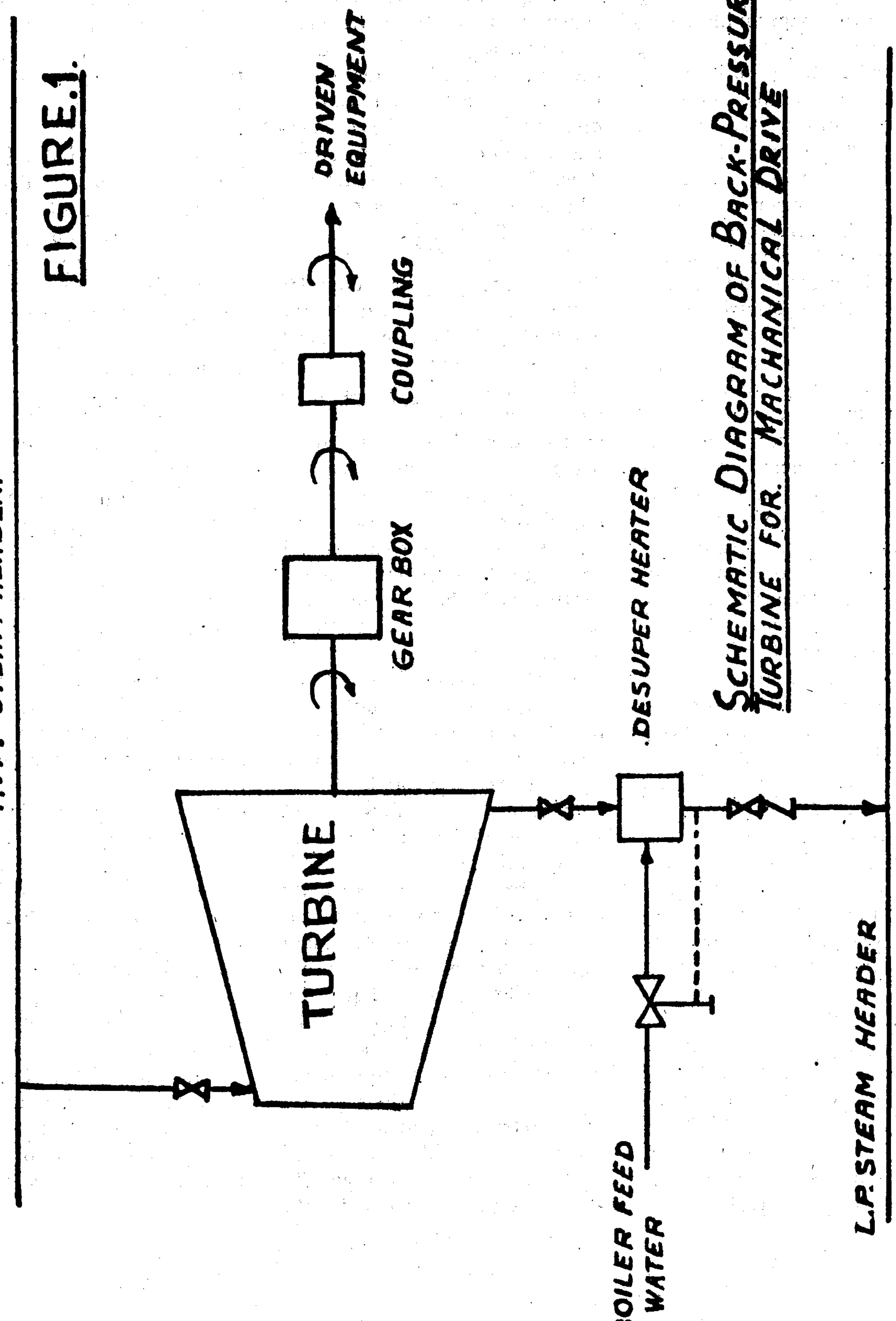
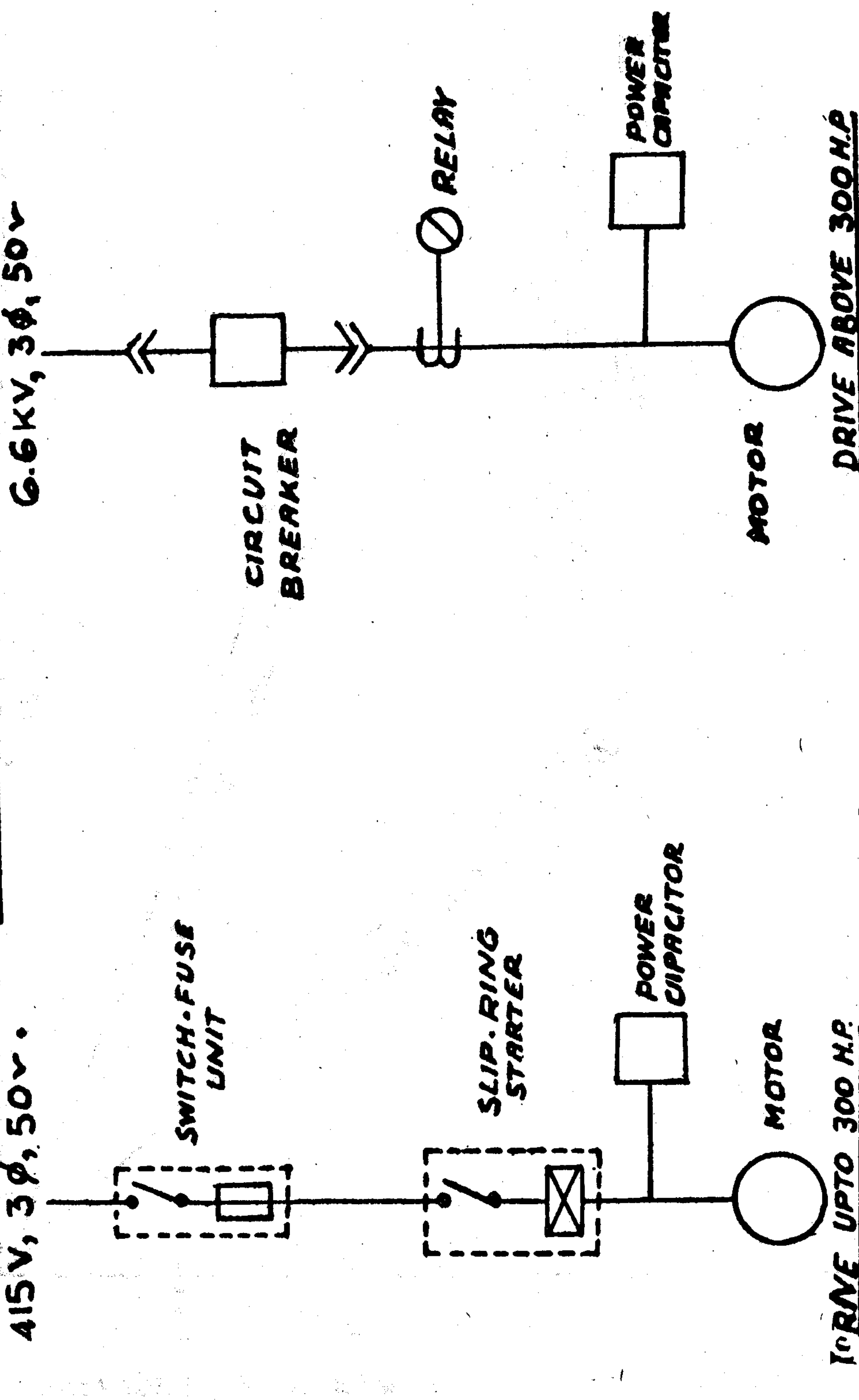


FIGURE.1.

SCHEMATIC DIAGRAM OF BACK-PRESSURE TURBINE FOR MACHANICAL DRIVE

FIGURE 2



SHEMATIC DIAGRAM FOR ELECTRIC MOTOR DRIVE

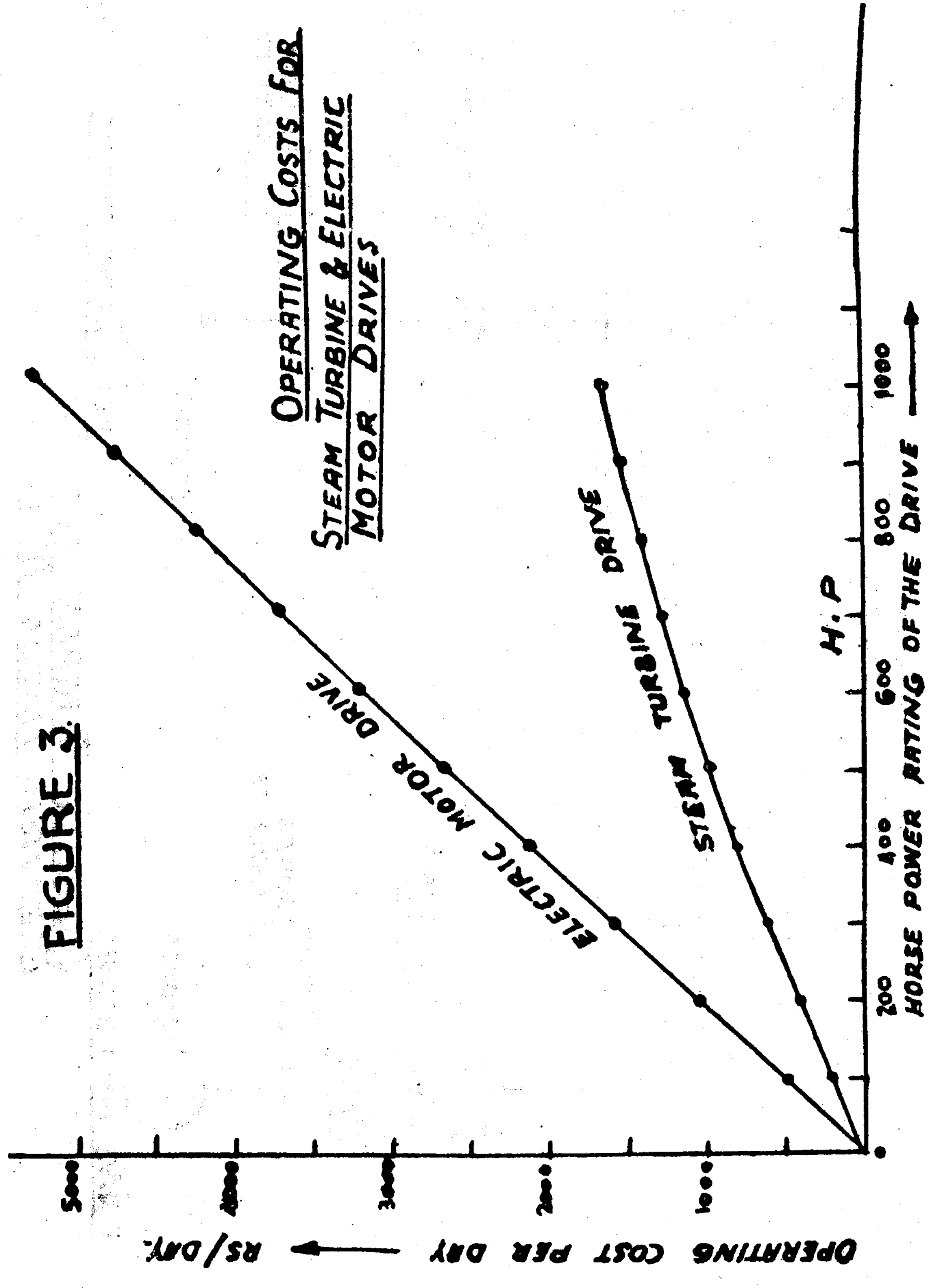
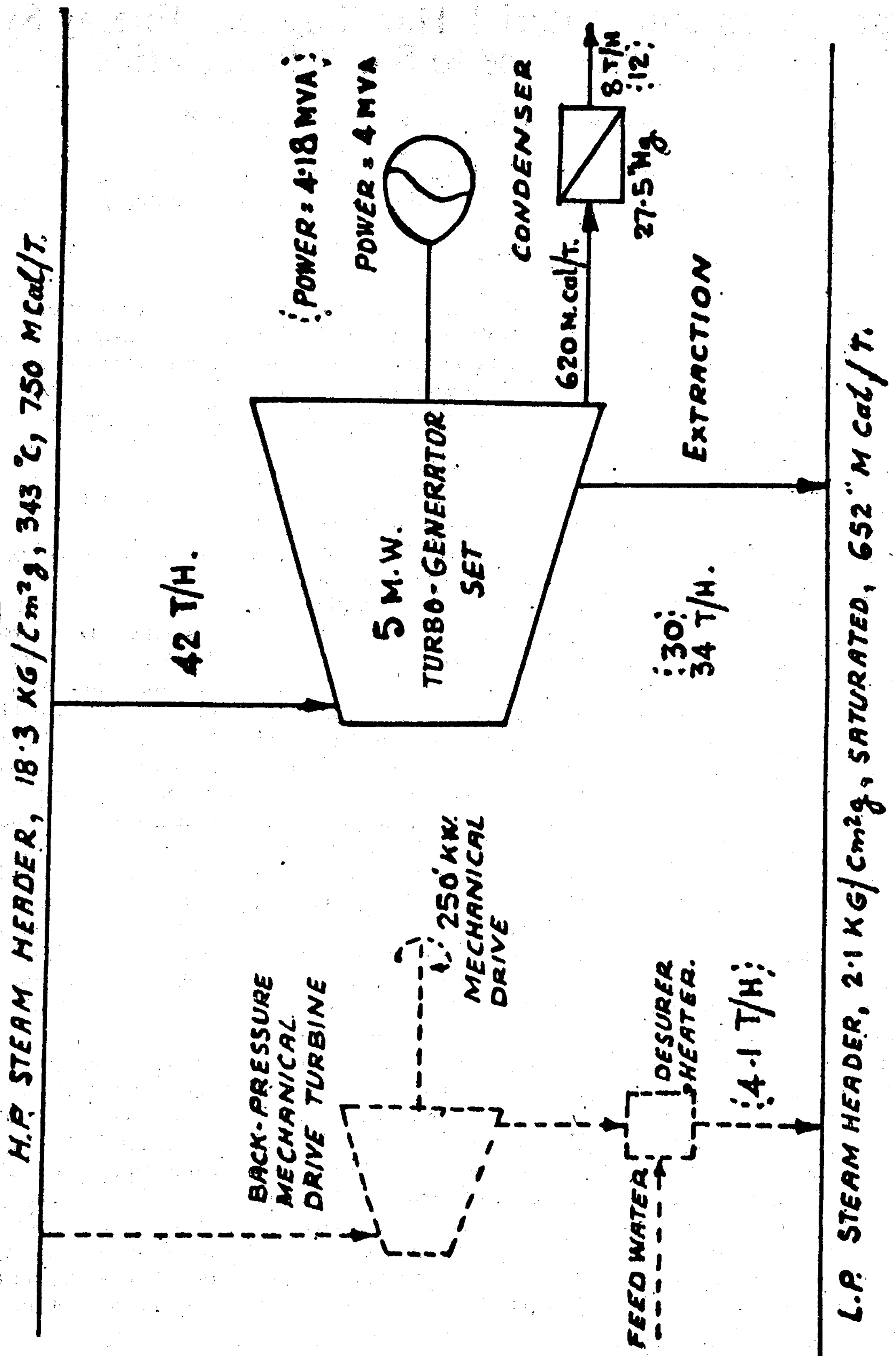


FIGURE 3

OPERATING COSTS FOR STEAM TURBINE & ELECTRIC MOTOR DRIVES



H.P. STEAM HEADER, 18·3 KG/Cm²g, 343 °C, 750 M cal/T.
42 T/H.
5 M.W.
TURBO-GENERATOR
SET
POWER: 4·18 MVA
POWER: 4 MVA
CONDENSER
620 M.cal/T.
27·5" Hg
8 T/H
12
EXTRACTION
30
34 T/H.
BACK-PRESSURE
MECHANICAL
DRIVE TURBINE
250 KW.
MECHANICAL
DRIVE
DESURER
HEATER.
4·1 T/H
FEED WATER
L.P. STEAM HEADER, 2·1 KG/Cm²g, SATURATED, 652 M cal/T.

FIGURE 4.