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Research Paper

ARTIFICIAL NEURAL NETWORK SIMULATION OF PRIME MOVER FOR THE ROLLING PROCESS IN THE THREE HIGH ROLLING MILLS

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There are various methods of power requirements on the basis of which motor rating and flywheel size of the rolling mill depend on three high rolling mills. These methods involve a lot of mathematical calculation useful in carrying out the static power energy requirement in rolling mill. The method selected here is based on mechanics of rolling which is widely used but this method also the tremendous mathematical work. Hence in this paper two software's were developed independently one for static analysis and other for the dynamic analysis of the rolling mill and both can be run independently or jointly for standard 8 hours working of the mill. A curve fitting algorithm was first utilized for approximating the actual load speed curve of a given motor as supplied by the manufacture and by using ANN simulation of the motor characteristics. The software can also invoke the ANN for the calculation of load speed characteristics. The conclusion obtained showed that the percentage of full load shared by induction motor a percentage of full load rating is higher for motor having higher rating. Based on this concept a design approach can be developed. For carrying out the dynamic analysis of the rolling process, first the static analysis was done where intensity of loading during a particular pass was studied. The energy requirement pattern and number of total passes in a fixed span of time is also ascertained. This static analysis forms the basis for dynamic analysis. The analysis was carried out by using Monte Carlo simulation approach.

Keywords: Artificial Neural Network (ANN), Flywheel, Rolling mill, Monte carlo simulation

INTRODUCTION

Neural Networks, which are simplified models of the biological neuron system, is a massively parallel distributed processing system made up of highly interconnected neural computing elements that have the ability to learn and thereby acquire knowledge and make it available for use. Neural Network are simplified

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imitations of the central nervous system, and obviously therefore, have been motivated by the kind of computing performed by the human brain. The structural constituents of a human brain termed neurons are the entities, which perform computations such as cognition, logical inference, pattern recognition and so on. Hence the technology, which has been built on a simplified imitation of imitation of computing by neurons of a brain, has been termed Artificial Neural Systems (ANS) technology or Arterial Neural Networks (ANN) or simply Neural Networks.

A human brain develops with time and this in common parlance is known as experience technically which involves the development' of neurons to adapt themselves to their surrounding environment, thus rendering the brain plastic in its information processing capability. On similar lines, the property of plasticity is also discussed with respect NN architectures, Further, we are also interested in the stability of an NN system, i.e., the adaptive capability of an NN in the face of changing environments.

In India we have most of the rolling mills as open train rolling mills where a single motor is used for roughing, intermediate and finishing mill. In this paper, an attempt is made to analytically estimate the static and dynamic behavior of the prime mover under the action of varying load of open train rolling mill and It is estimated that the static and dynamic power requirement of rolling mill varies from 100 to 800 HP depending on the product being rolled and the size of input billets. The analysis was carried out by using Monte Carlo simulation approach. The Monte Carlo simulation simulates the entire loading cycle for the overall working of the machine for a finite duration of around 10 to 20 minutes.

A software is developed for static analysis and then dynamic analysis of the rolling mill. A algorithm was utilized for approximating the actual load speed curve of a given motor as supplied by the manufacture (IS 325-1978) and by using the ANN simulation of the motor characteristics. The ANN Simulation computer software is used to evaluate the energy requirement of such process for each second over the entire span for which the simulation was done. The software can also give second wise flywheel energy demand for operation of the mill over the selected time span. The occurrence of peak energy demand from the graphical results of dynamic analysis of the rolling operation and its intensity can now be used for the optimum selection of the drive combination of induction motor and a flywheel for the rolling mill. Based on the conclusion obtained a design approach is developed for the conservation of energy in this area.

For carrying out the dynamic analysis of the rolling process. first the static analysis was done where intensity of loading during a particular pass was studied. The energy requirement pattern and number of total passes in a fixed span of time is also ascertained. This static analysis forms the basis for dynamic analysis. The analysis was carried out by using Monte Carlo simulation approach. The inter arrival timings of loadings of the machine for each ingot, as their individual energy consumption was already known from the static analysis.The occurrence of peak energy demand from the graphical results of dynamic analysis of the rolling operation and its intensity can now be used for the optimum selection of the drive combination of induction motor and a flywheel for the rolling mill.

BACK PROPAGATION ALGORITHM

The back propagation algorithm works in much the same way as the name suggests. After propagating an input through the network, the error is calculated and the error is propagated back through the network while the weights are adjusted in order to make the error smaller. Although we want to minimize the mean square error for all the training data, the most efficient way of doing this with the back propagation algorithm, is to train on data sequentially one input at a time, instead of training on the combined data. However, this means that the order data is given importance, but it also provides a very efficient way of avoiding getting stuck in local minima.

First the input is propagated through the ANN to the output. After this the error e_k on a single output neuron k can be calculated as:

$$e_k = d_k - y_k$$

where y_k is the calculated output and d_k is the desired output of neuron k. This error value is used to calculated a ∂_k value, which is again used for adjusting the weights. The ∂_k value is calculated by:

$$\delta_k = e_k g'(y_k)$$

where g is the derived activation function

when the ∂_k value calculated, we can calculate the ∂_j values for preceding layers. The ∂_j values of the previous layer is calculated from the ∂_k values of this layer, by using the following equation:

$$\delta_j = \eta\, g'(y_j)\sum_{\hbar=D}^{k} \delta_{\hbar} w_{j\hbar}$$

where K is the number of neurons in this layer and η is the learing rate parameter, which determines how much the weight should be adjusted. The more advanced gradient descent algorithms does use a learning rate, but a set of more advanced parameters that makes a more qualified guess to how much the weight should be adjusted. By using the ∂ values, the Δ_u values that the weights should be adjusted by and can be calculated by:

$$\Delta w_{jk} = \delta_j y_k$$

the Δw_{jk} value is used to adjust the weight wjk by $w_{jk} = w_{jk} + \Delta w_{jk}$ and the back propagation algorithm moves on to the next input and adjusts the weights according to the output. This process goes on until a certain stop criteria is reached. The stop criteria are typically determined by measuring the mean square error of the training with the data, when this mean square error reaches a certain limit, the training is stopped. More advanced stopping criteria involving both training and testing data are also used.

SPEED TORQUE CHARACTERISTICS OF AN INDUCTION MOTOR

The Induction motor is a there phase AC motor and is the most widely used machine in the rolling mills. It has basically two parts-Stator and Rotor. The Stator is made up of a number of stampings with slots to carry three phase windings. It is wound rotor has three-phase, windings. It is wound for a definite number of poles. The windings are geometrically spaced 120 degree apart. Two types of rotors are used in induction motors-squirrel cage rotor and wound rotor.

A squirrel-cage rotor consists of thick conducting bars embedded in parallel slots. These bars are short-circuited at both ends by means of short-circuiting rings. A wound rotor has three-phase, double-layer, distributed winding. It is wound for as many poles as the stator. The three phases are winded internally and the other ends are connected to slip-rings mounted of shift with brushes resting on them. The brushes are connected to an external resistance that does not rotate with the rotor and can be varied to change the N-T characteristics.

Initially when the motor starts, the slip is high. So $k_2/s = 0$.Hence the torque product is proportional to the speed N_m. However when the motor attains stable speed, slip is negligible. Hence $k_3.s = 0$ and the torque is inversely proportional to the speed N_m. From these relationships, the general shape of speed-torque characteristics of Induction motor can be obtained.

APPLYING ANN TO AN INDUCTION MOTOR

The input of slip v/s torque relationship data as shown in Figure 1 is fed into the ANN software. When ANN is applied to the whole graph them results obtained are poor. So the data has been divided into two parts. In first part increasing values of torque are considered and in second part decreasing values of torque are taken. For this purpose whole graph of slip v/s torque has been divided onto 36 points. In the first part 17 points (in increasing order of torque) of the slip v/s torque are given to ANN and its corresponding output and graph is obtained. And in the second part remaining 20 points (in decreasing order of torque) are fed and its corresponding output of and its graph is obtained. Joining of graph is taken common in both parts.

Slip v/s Torque characteristic graph is divided into 36 small parts. Points obtained are shown in Table 1.

Figure 1: N-T Curve of Induction Motor

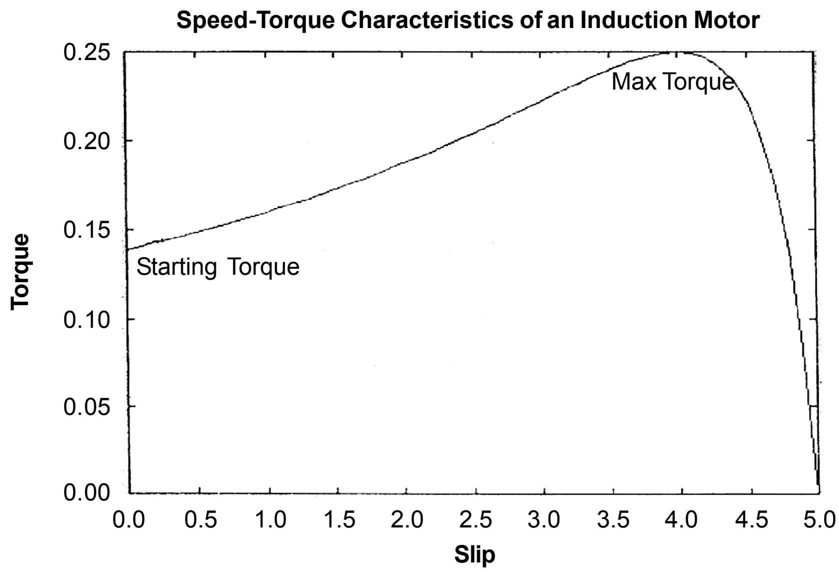


Table 1: Value of Slip V/S Torque Characterstics Curve

S. No.	% Slip	Torque	S. No.	% Slip	Torque
1.	0.000000	0.137784	19.	4.308035	0.238636
2.	0.491071	0.144886	20.	4.419643	0.230114
3.	0.558036	0.149148	21.	4.531250	0.215909
4.	0.825893	0.156250	22.	4.620536	0.200284
5.	1.116071	0.161932	23.	4.665178	0.184659
6.	1.383929	0.169034	24.	4.709822	0.167614
7.	1.651786	0.176136	25.	4.754464	0.156250
8.	1.919643	0.184659	26.	4.799107	0.142756
9.	2.187500	0.191761	27.	4.821429	0.129972
10.	2.455357	0.201705	28.	4.843750	0.113636
11.	2.678571	0.210227	29.	4.888393	0.098011
12.	2.946429	0.218750	30.	4.910714	0.082386
13.	3.214286	0.230114	31.	4.915179	0.068892
14.	3.571429	0.238636	32.	4.933036	0.053977
15.	3.705357	0.244318	33.	4.955358	0.039773
16.	3.861607	0.247159	34.	4.966518	0.023438
17.	3.995536	0.250000	35.	4.977678	0.011364
18.	4.107143	0.247159	36.	5.000000	0.000000

The first input 17 values given to ANN and its corresponding output values

No. of inputs = 1 (slip)

No. of hidden layers = 5

No. of outputs = 1 (Torque)

No. of data = 17

The output of the first 17 values and its graph are:

Weight obtained are V(1, *m*) = 0.99597 0.90236, –0.99597, –0.99597, 0.90236

W(*m*, *n*) = –5.38951, 4.72527, –5.38951, –5.38951, 4.72527

For the purpose of simulating the behavior of induction motor, Back propagation algorithm of ANN is used. ANN software for back propagation algorithm is run for number of iterations until errors become constant. Numbers of iterations tried are 50,000 results obtained are shown in Table 2.

Table 2: Actual Input and Output Relationship Obtained from ANN

% Slip Input	Torque Output	Torque Calculated	% Slip Input	Torque Output	Torque Calculated
0.000	0.138	0.14155	2.433	0.202	0.20241
0.268	0.145	0.14340	2.679	0.210	0.21156
0.558	0.149	0.14633	2.946	0.219	0.22031

Table 2 (Cont.)

% Slip Input	Torque Output	Torque Calculated	% Slip Input	Torque Output	Torque Calculated
0.826	0.156	0.15021	3.214	0.229	0.22752
1.094	0.163	0.15551	3.482	0.240	0.23321
1.362	0.169	0.16243	3.683	0.244	0.23659
1.652	0.176	0.17179	3.839	0.247	0.23876
1.920	0.185	0.18184	3.973	0.250	0.24034
2.188	0.193	0.19260			

The total Iterations are 50,000 and the error rate = 0.03828. The Table 3 shows the errors per training set (first seventeen values).

Table 1 shows the whole 36 points of slip vs. torque relationship. In Table 2, 17 points of first part are shown. Table 2 and Figure 2 compares the actual values of output (torque) and calculated values from ANN of torque. Table 3 shows the error rate of ANN for each point. It can be seen from Table 2 and Figure 2 that results obtained are good. Error between actual and calculated values of toque is minimum. The Second part of slip v/s torque Graph is shown in Table 4.

The total No. of inputs = 1 (slip), No. of hidden layer 5, No. of output = 1 (torque) and No. of data = 20. The output of second 20 values and its graph is shown in Figure 2. The

Figure 2: Graph of Slip V/S Torque Actual and Calculated By ANN (First Seventeen Values)

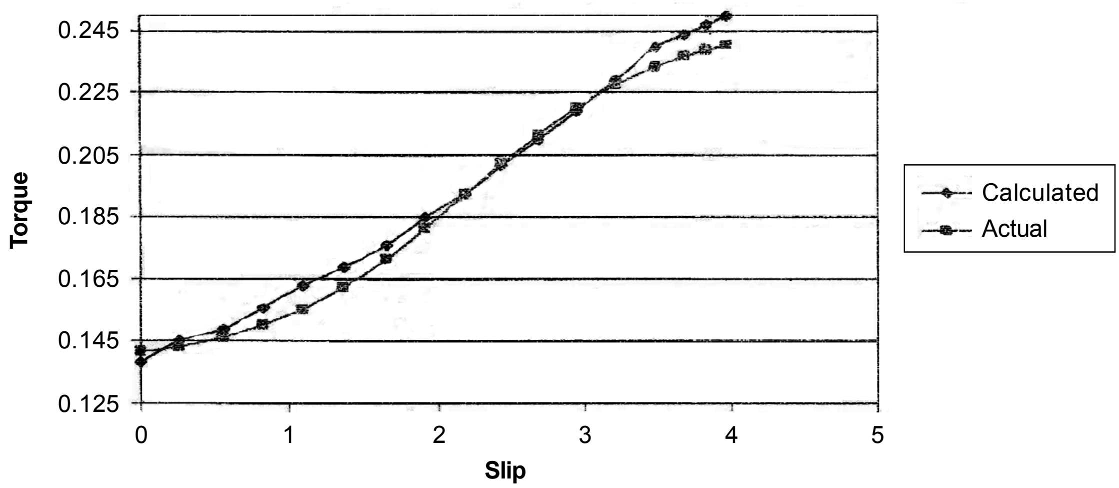


Table 3: Errors per Training Set (First Seventeen Values)

0.03360	0.06360	0.00523	0.01675	0.08610
0.01327	0.05884	0.00007	0.06097	
0.02509	0.03871	0.01190	0.06887	
0.05328	0.02516	0.01390	0.07487	

Table 4: Actual Input Output Relationship Obtained from ANN

S. No.	% Slip	Torque	S. No.	% Slip	Torque
1.	3.973214	0.250000	11.	4.821429	0.129972
2.	4.107143	0.247159	12.	4.843750	0.115057
3.	4.285715	0.238636	13.	4.866071	0.098011
4.	4.419643	0.230114	14.	4.910714	0.080966
5.	4.531250	0.215909	15.	4.921875	0.068182
6.	4.620536	0.198864	16.	4.933036	0.053977
7.	4.665178	0.184659	17.	4.955358	0.038352
8.	4.709822	0.167614	18.	4.966518	0.023438
9.	4.754464	0.156250	19.	4.977678	0.011364
10.	4.799107	0.142756	20.	5.000000	0.000000

weights are $V(1, m)$ = –2.85365, 1.85222, –2.85365, –2.85365 and –2.85364 and $W(m, n)$ = 11.34096, –4.65701, 11.34101, 11.34095 and 11.34081. For the purpose of simulating the behavior of induction motor, Back propagation algorithm of ANN is used. ANN software for back propagation algorithm is run for number of iterations until errors become constant. No of iterations tried are 50,000 and the results obtained are shown in Table 5.

Table 5: Actual Input Output Relationship Obtained from ANN

% Slip Input	Torque Output	Torque Calculated	% Slip Input	Torque Output	Torque Calculated
3.973	0.250	0.25000	4.821	0.115	0.13093
4.107	0.247	0.25000	4.844	0.098	0.11572
4.286	0.239	0.24999	4.866	0.081	0.10148
4.420	0.230	0.24976	4.911	0.068	0.07687
4.531	0.216	0.24732	4.933	0.054	0.07159
4.621	0.199	0.23681	4.955	0.038	0.06666
4.665	0.168	0.22429	4.967	0.023	0.05780
4.710	0.156	0.20457	4.978	0.011	0.05384
4.751	0.143	0.17778	5.000	0.000	0.05017
4.799	0.130	0.14671			

The total iterations = 50,000 with error rate = 0.07257, and old error rate = 0.07257

Table 1 shows the whole 36 points of slip v/s torque relationship. In Table 5, 20 points of second part are shown in Table 5 and Figure 3 compares the actual values of output (torque) and calculated values from ANN of torque. Table 6 shows the error rate of ANN each point. It can be seen from Table 4 and Figure 3 that results obtained are good. Error between actual and calculated values of torque is minimum. Weights obtained from ANN for both the parts are fed into author's main software. A sub program is also combined in

Figure 3: Graph of Slip V/S Torque Actual and Calculated by ANN (Second Part)

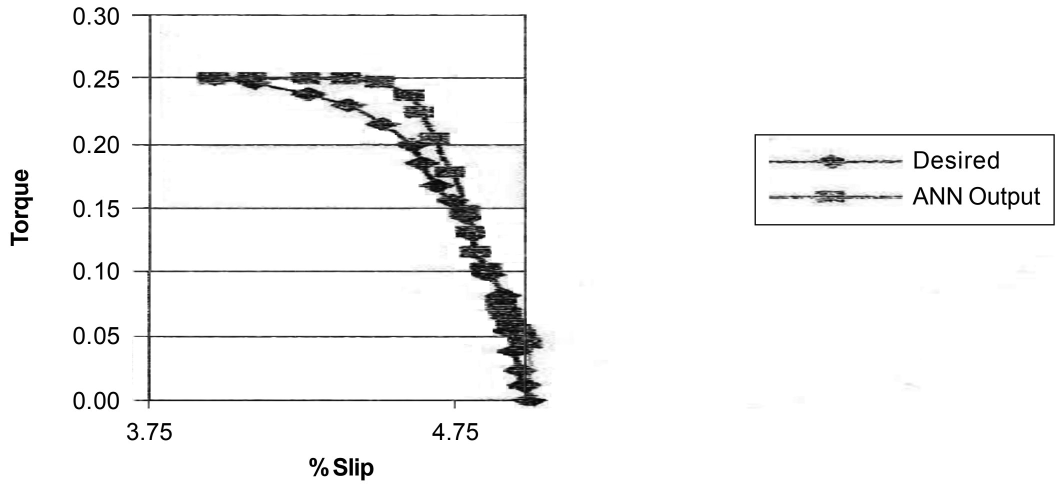


Table 6: Errors per Traiing Set (Second Twenty Values)

0.00000	0.00384
0.01136	0.00265
0.04543	0.01387
0.07859	0.01638
0.12566	0.01364
0.15180	0.05073
0.15853	0.77770
0.14783	0.12159
0.08613	0.15522
0.01581	0.17459

main software for interpolating the value of torque from slip value. For interpolation purpose, sub program checks whether the value of slip is more or less than 3.973. It automatically runs the first part and calculates corresponding value of torque and in case of value of slip more than 3.973, it goes into second part and takes weights in second part and calculates the corresponding value of torque.

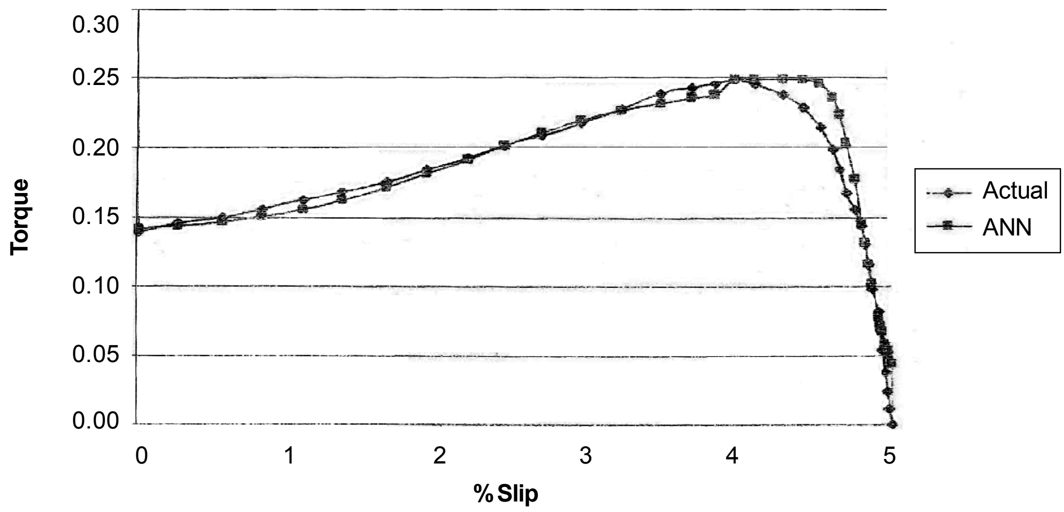
As it is stated that both parts of the graph will be dealt separately. When the value of % slip is less than 3.973 then for torque calculation weights will be considered for ANN as obtained in first part of the graph. If value of slip is equal to or greater than 3.973 then weights will be considered as obtained in second part of the graph in ANN calculation. When both the parts are combined and comparison of desired values and values calculated from ANN are shown in the Figure 4.

APPLICATION OF SOFTWARE FOR THE ROLLING PROCESS

The software developed for static and dynamic analysis of the high open train rolling was applied for the simulation of the rolling process for the manufacturing 16mm round bar from the 90 mm × 90 mm billet.

The pass sequence used for the above analysis is chosen to be standard pass sequence normally deployed in the commercial rolling mill which is in practice. The pass sequence is given for each product as given for each product as given

Figure 4: Graph Shown Actual and ANN Output of Slip Torque Curve



below from the Table 7 and the corresponding energy requirement, power requirement and rolling time is given in the Table 8.

Table 7: Roll Pass Sequence for 16 mm Round Bar

Pass No.	Input Size	Output Size	Pass No.	Input Size	Output Size
1.	90 × 90	75 × 92	10.	47 × 21	32 × 25
2.	92 × 76	75 × 82	11.	25 × 32	16 × 40
3.	82 × 75	83 × 89	12.	40 × 16	26 × 20
4.	83 × 53	56 × 59	13.	20 × 26	14 × 30
5.	59 × 56	32 × 77	14.	30 × 14	21 × 18
6.	77 × 32	47 × 77	15.	18 × 21	14 × 23
7.	40 × 47	21 × 60	16.	23 × 14	16 × 17
8.	60 × 21	32 × 28	17.	17 × 16	16 × 16
9.	28 × 32	21 × 47			

Table 8: Static Power Consumption of 16 mm Round Bar

Energy Drawn per Pass	Power Reqd per Pass	Time Taken per Pass
105.32940	321.8671	0.3272450
137.15660	357.0325	0.3841572
67.59201	151.6017	0.4458525
195.72900	394.4305	0.4962319
243.93240	379.0268	0.6435755
222.96820	240.3893	0.9275297

Table 8 (Cont.)

Energy Drawn per Pass	Power Reqd per Pass	Time Taken per Pass
364.88490	330.87930	1.102774
260.73600	154.50120	1.687598
215.11630	92.96879	2.313855
212.50800	98.63997	2.154381
302.81850	122.69240	2.468112
245.29940	75.18289	3.262702
269.72020	71.03329	3.797096
255.50570	51.76136	4.936225
225.33430	43.13842	5.223518
278.22620	45.06449	6.173955
87.94819	12.03307	7.308874

Note: Static Power Consumption in Kw.h/ton = 22.7827500.

The Tables 7 and 8 shows the dynamic power consumption second wise in an hour/ flywheel energy stored for 200 HP motor powers. This is calculated by the software model developed for this purpose.

From the Figure 5 for 630th second the value is 17 which means 17 × 50 = 850 HP-Sec (actually the values are 1/50 of the actual demand and this has been done for the purpose of printing). This much quantity of energy is required by the rolling system at that second because the prime movers cannot supply adequate energy at this second hence system draws 850 HP-Sec energy from the flywheel which stores approximately 8000 to 10000 HP-Sec energy. The zeros in the table indicates that the rolling mill is purely run by prime movers and the flywheel is rotating at its rated rpm.

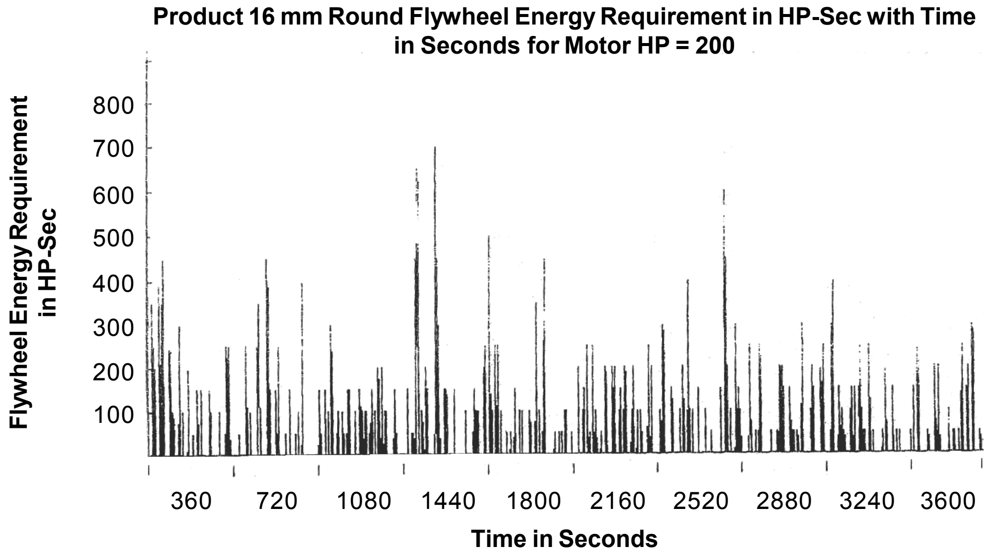
DYNAMIC SIMULATION RESULTS

Tables 7 and 8 gives the dynamic simulation results for the rolling of the product 16 mm round starting from 90 mm × 90 mm with an assumption that the rolling mill is fitted with a 200 HP electric induction motor. The rolling process can be again simulated with 250 HP to 300 HP motor and similar table gives the dynamic simulation results.

Figure 5 shows the flywheel energy requirement in HP-Sec with time in seconds for product 16mm round using 200 HP motor. Hence the ordinate shows ply wheel energy demand of the rolling mill an any instant whereas abscissa shows the time in second, Similar dynamic analysis can be by using the same software for the simulation of the rolling process for rolling produces like 16 mm round, 20 mm × 5 mm plate, 8 mm square, and 40 mm × 40 mm × 5 mm angle by using different sizes of motor from 250 HP to 300 HP.

Table 9 shows the summary of the flywheel energy demand for rolling 16 mm round for different sizes of motor. Entry one in row 1 column 1 indicates that while rolling 16 mm round starting from 90 mm × 90 mm billet using 200 HP motor, the flywheel energy demand

Figure 5: Graph Shown Flywheel Energy Requirement in HP-Sec with Time in Second for 16 mm Round Bar in 200 HP Motor



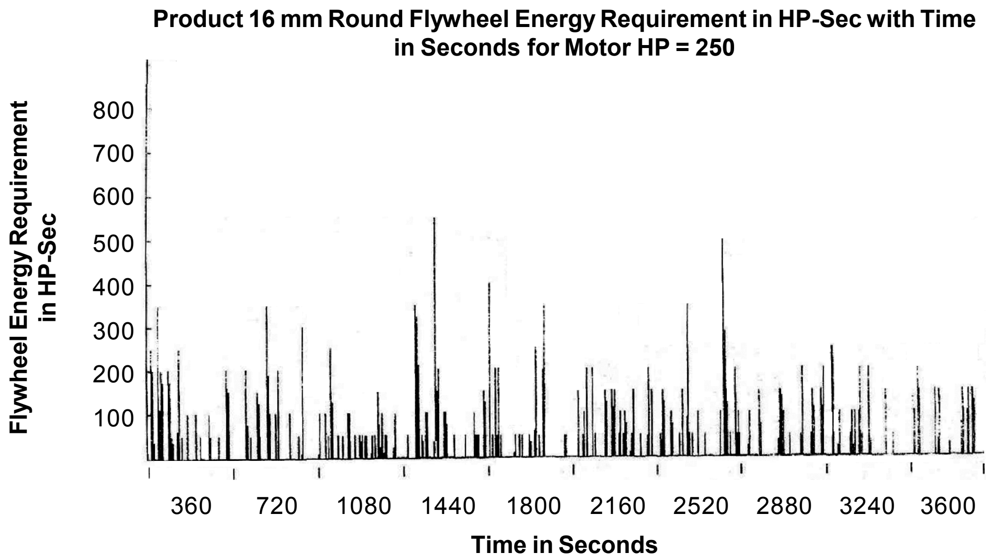


Table 9: Products 16 mm Round Bar

Motor HP	No. of Secs. in Hour When Flywheel Demand Exceeds Following HP-Sec Value									
	150	200	250	300	350	400	450	500	550	600
200	217	151	97	60	42	31	21	17	14	9
250	98	60	35	20	16	10	9	8	3	2
300	37	20	11	8	4	4	4	1	1	0

exceeds the value of 150 HP sec 217 times in a span of one hour. Similarly row 1 column 10 shows entry value 9 which indicates that flywheel energy demand exceed 600 HP sec

9 times in an hour. Likewise if the same product is to rolled by 300 HP motor it never exceeds 600 HP sec in an hour.

CONCLUSION

From the results of dynamic analysis it is clear that at the most 250-300 HP motor with an average of 400 rpm and flywheel of 10 tons can meet the energy requirement of 9" rolling mill for almost all the products. It is also clear from the dynamic analysis that instruments demand can be high. But such instances are very rare and hence employing a higher size motor only for such stay occurrences is not advisable.

Tables 7 and 8 shows that the static energy consumption in every pass for a particular rolled product. When all static energy figures for all passes are summed up. We get total static energy required for a particular product. It can be expressed in kw-h/ton for every product. Figure 5 shows that in one hour of rolling the flywheel energy demands exceed a particular HP-Sec value for how many times of for how many seconds also the flywheel response in terms of energy demand for different values of motor horse power like 200 HP, 250 HP and 300 HP, the flywheel energy demand may be similarly calculated for all the products. From the Figure 5, it is seen that for m any of the seconds the flywheel energy demand is zero. This means that at those seconds the motor power is more than the demand energy of the system and hence no energy is supplied by the flywheel. Only when the energy demand of the systems exceeds over the motor power flywheel supplies energy and has shown by the instantaneous peaks in the graphs. During the idle running of the rolling mill (idle time is much more the actual rolling time. As us evident from the gaps between the peaks of energy demand also from the time for each pass values of static analysis) flywheel receives energy from the systems. It is also experimentally verified that when flywheel supplies energy its rpm is reduced and when it receives energy its rpm increased.

From economic consideration, the running cost of correct size motor is 10-12% less than the oversize motor which is fitted in these mills. When average monthly bills of rolling mills were examined it is approximately saving of 10 to 12% is straight saving per month. Hence analysis of the rolling mill will be of great help to the rolling mill industry.

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