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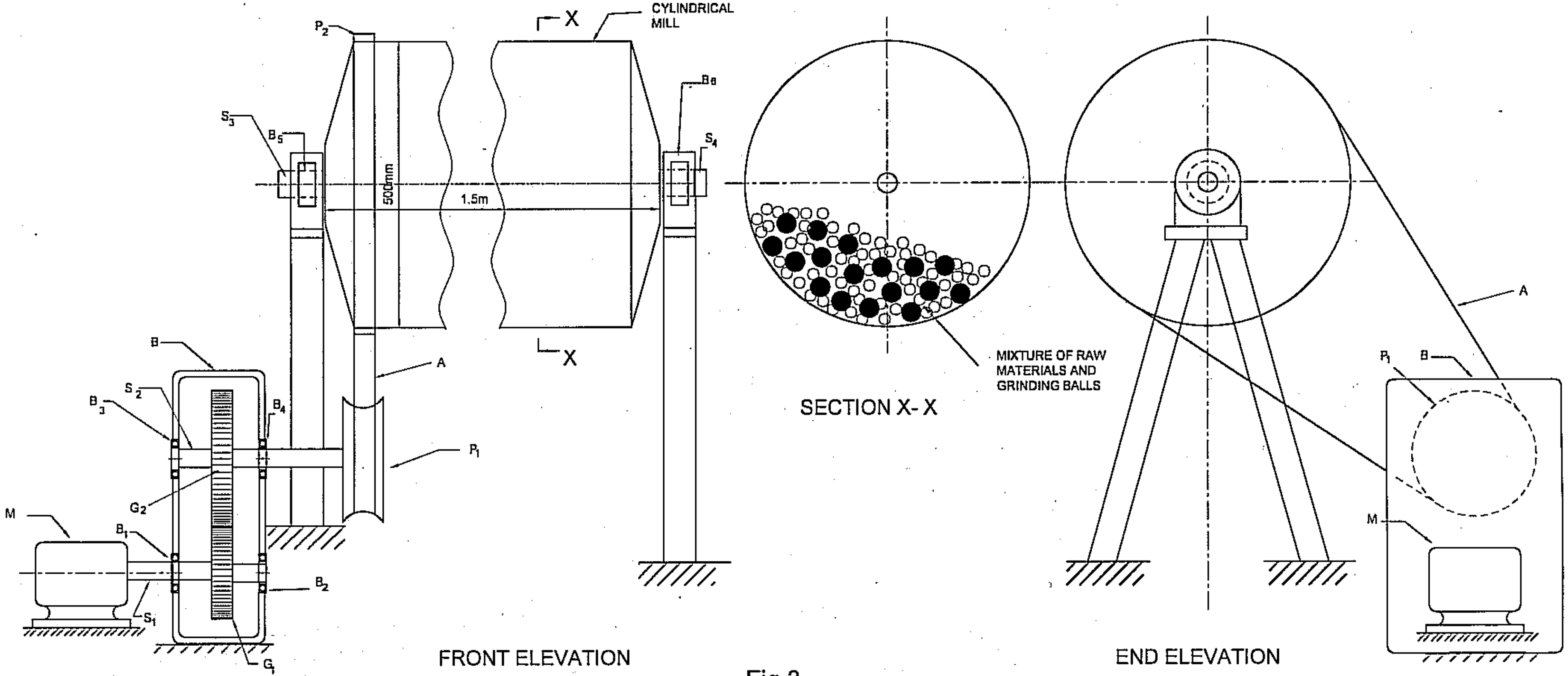
THE OPEN UNIVERSITY OF SRI LANKA
FACULTY OF ENGINEERING TECHNOLOGY
DIPLOMA IN TECHNOLOGY – LEVEL 04
FINAL EXAMINATION – 2009/2010
MEX4231–ELEMENTARY MACHINE DESIGN – PAPER II

DATE : MARCH 05, 2010
TIME : 0930HRS. – 1330HRS.
DURATION : FOUR HOURS

READ THE FOLLOWING INSTRUCTIONS CAREFULLY BEFORE ANSWERING THE QUESTION PAPER

1. *This question paper has only one question. Answer all parts of the question.*
2. *Devote 15 to 20 minutes to read and understand the question carefully.*
3. *.Wherever appropriate, use catalogues, tables, data sheets and charts provided to you at the examination hall. State in the answer clearly if you extract and use any data or information from such literature to support design calculation..*
4. *At the end of the examination, hand over all such literature to the supervisor or an invigilator.*
5. ***Any missing data may be sensibly and reasonably assumed, provided that such data are clearly stated with reasons to accept them.***
6. *Any ideas/opinions presented in the form of neatly drawn sketches are welcome in place of written representation.*
7. *Any results from calculation should be presented with their correct units, unless they are dimensionless. All such results s should be underlined.*
8. ***It is important that candidates answer all parts of the question listed in that given order in the question.***



FRONT ELEVATION

SECTION X- X

END ELEVATION

Fig.3

Question

A ceramic product manufacturer requires expanding his business to meet the growing demand for his products. The Fig.1 shows the main processes involved in the product manufacturing line, namely, *1*. crushing, *2*. cleaning, *3*. forming and *4*. firing.

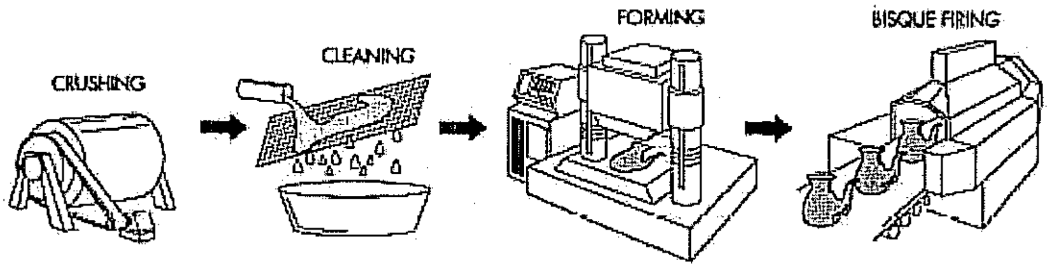


Fig.1: Main stages of manufacturing porcelain products.

In a method study exercise, it was identified that there exists a bottleneck at the crushing stage. As a result, the management has given more consideration to improve output capacity at the crushing stage, wherein slurry of raw materials, such as Dolomite, Feldspar, Silica, Clay, etc, is made. It is then cleaned and formed into required shapes. These raw materials are available in average 20 *mm* particles and needed to be ground to an average size of 20-70 *microns*. The most popular machine for this operation is the BALL MILL.

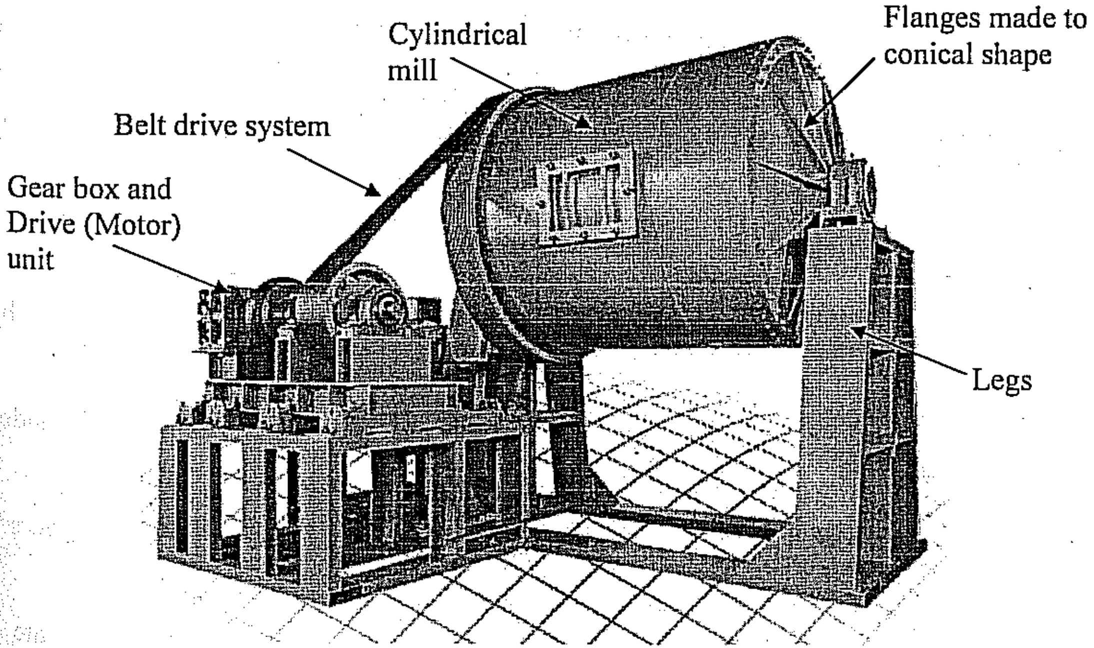


Fig.2: A belt driven ball mill.

Ball mill, shown in Fig.2, is a crusher used for crushing/grinding many materials into fine powder and the cylinder shown plays the important role of crushing/grinding and mixing of the raw materials. Ball mills rotate around a horizontal axis, and are partially filled with the material to be crushed together with the grinding medium. Different materials are used as grinding media including ceramic balls, flint pebbles and stainless steel balls. When the cylinder rotates, due to the centrifugal force the steel balls are carried to some height away from its axis and fall back. This action repeats making the raw material ground, crushed and mixed. . An internal cascading effect reduces the material to a fine powder. The balls as well as the raw material are charged and discharged through openings in the cylinder wall. Industrial ball mills can operate continuously. The rotation is usually 4 to 20 revolutions per minute, depending upon the diameter of the mill. The above is an introduction to the ball mill and its function.

The management advised its engineers to study the existing ball mill, design a new one and check the feasibility of manufacturing a new ball mill to required specifications. They proposed an arrangement of which a sketch is shown in Fig.3. It is a horizontal type ball mill consisting of feeding part, discharging part, mill (cylindrical part), and the drive unit. The drive unit consists of a V-belt drive, gear arrangement and an electric motor as the prime mover. The feeding and discharging hoppers are not shown in Fig.3.

The shell of the cylindrical mill is fabricated with steel plates and is fastened to conical shaped end plates at both ends. The mill is to be driven by a single or three phase motor **M**. The motor supplies power via a gear mechanism **B** and a V-belt drive arrangement **A**. The driver pulley **P_1** is keyed to the power output shaft S_2 of the gear box, and the driven pulley **P_2** is fixed to the cylinder mill as an integral part. The motor shaft is coupled to the power input shaft of the gear box S_1, which carries the driver gear **G_1**. The power output shaft S_2 carries the driven gear **G_2**. Each shaft **S_1** and **S_2** are positioned using a pair of bearings identified as **B_1**, **B_2** and **B_3**, **B_4** respectively. This cylindrical part, having two short axels S_3 and S_4 at its two ends, is mounted using suitable bearings **B_5** and **B_6** on two supports which are in turn erected on the ground. .

Some of the important design requirements are given below,

1. For optimum grinding of raw materials it is needed to have 500 *kg* of balls (grinding media) for each production cycle.
2. The fraction of critical rotational speed, **C_s**, of the cylindrical mill is considered as 0.65.
3. The machine is intended to run for 5 years, 25 days per month and 8 hours per day continuously.
4. An empirical equation that has been derived by Erdem et.al. to calculate the power required to drive a ball mill for a metric ton of balls, is given by,

$$P_B = 4.879 \times D^{0.3} \times (3.2 - 3V_B) \times C_s \times \left(1 - \frac{0.1}{2^{(9-10\times C_s)}}\right) + S_B$$

Where,
P_B – required power in kilowatts per metric ton of balls
D – mill diameter in meters
V_B – fraction of cylinder volume loaded with balls
C_s – fraction of critical speed
S_B – ball size factor

5. Considering the capacity of the ball mill, 40% of the total mill-volume is occupied by the balls, and this can be considered as the fraction of the mill volume $\mathbf{V_B}$ loaded with balls.
6. Dimensions of the cylinder mill; Diameter **(D)** = 500*mm*, Length **(L)** = 1.5*m*.
7. It is assumed that the balls and raw material are evenly distributed along the length of the mill.
8. Ball size factor, $\mathbf{S_B}$, is given as 0.25.

Answer the following questions.

1. Estimate the theoretical power required to drive the ball mill for crushing and grinding action.
2. Estimate the required motor power needed to drive the ball mill, considering the mechanical inefficiencies, hence select a suitable electric motor as the prime mover.
3. Propose a suitable belt drive system with standard pulleys.
4. Select a suitable key for the drive pulley $\mathbf{P_1}$.
5. Design the gear train completely from the point of strength, wear and dynamic loads.
6. Recommend a suitable pair of rolling-element bearings ($\mathbf{B_1}$and $\mathbf{B_2}$) to support the drive shaft $\mathbf{S_1}$.
7. Determine the minimum diameter of the power output shaft $\mathbf{S_2}$ in the gear enclosure.

9. Draw the free body diagram of the forces and torques on the axels S_3 and S_4, fixed at the both sides of the cylindrical mill.

10. From looking at the sketch what are the drawbacks of the proposed design? Suggest improvements which can be effected on the proposed design.

The following information is provided in support of the design analysis, where all data and equation given below may or may not be needed for your calculations. Apart from the data given below you are provided with, *1.* Instruction booklet of spur and helical gear design, *2.* Motor catalog, *3.* Bearing selection manual, *4.* Handbook of metric keys and keyways and *5.* Handbook of V-belt drives.

Please note that you are given only basic formulae and such formulae need to be further dealt with before applying them appropriately.

Power transmission efficiencies are:

Electric motor : 85%
Belt Drive : 90%
Gear Drive : 95%

Density of steel: 7.8×10^3 kg/m^3

Design shear stress = 0.3 x yield stress in tension
= 0.18 x ultimate stress in tension or which ever smaller.

Design value of the normal stress = 0.36 x ultimate stress in tension
= 0.6 x yield stress in tension
or which ever smaller.

- If necessary select one of the following steels for the shaft material

AISI Number	Yield strength (MN/m^2)	Ultimate tensile strengths (MN/m^2)
1010	303	366
1018	373	442
1045	532	626
4340	683	766

If key ways are present then values are to be reduced by 25%.

For ductile materials Yield stress in shear = 0.5 x yield stress in tension.

- A shaft having a diameter d, when subjected to combined bending and torsion the equivalent bending, and torsional stresses at any point on the shaft are,

$$\tau_{eq} = \frac{16}{\pi d^3}\left[K_b M + \sqrt{(K_b M)^2 + (K_t T)^2}\right]$$

$$\text{and } \tau_{eq} = \frac{16}{\pi d^3}\left[(K_b M)^2 + (K_t T)^2\right]^{\frac{1}{2}}$$

	k_b	k_t
For Stationery shafts:		
Load Gradually applied	1.0	1.0
Load Suddenly applied	1.5 to2.0	1.5 to 2.0
For Stationery shafts:		
Load Gradually applied	1.5	1.0
Load Suddenly applied (minor shock)	1.5 to 2.0	1.0 to 1.5
Load Suddenly applied (heavy shock)	2.0 to 3.0	1.5 to 3.0

$$\sigma_n(\max) = \frac{\sigma_x + \sigma_y}{2} + \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^{\ 2}}$$

$$\sigma_n(\min) = \frac{\sigma_x + \sigma_y}{2} + \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^{\ 2}}$$

$$\tau(\max) = \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^{\ 2}}$$

- For gears, basic Louis Equation is :

$$F = s\,b\,P_c\,y$$

For ordinary design conditions, the face width is limited to a maximum of 4 times the circular pitch. Letting $b = kP_c$, where the factor, $k \leq 4$,

$$F_d = \frac{21V(bC + F)}{21V + \sqrt{bC + F}} + F$$

Where, F_d = dynamic load, N
V = pitch line velocity, m/s
b = face width, m
$$F = \frac{\text{gear torque}}{\text{pitch diam, of gear}} = 2M_t / D$$
C = a constant, in N/m

$$F_w = D_P\, b\, K\, Q$$

Where, D_p = pitch diameter of smaller gear (pinion), m
b = face width of gear, m
K = stress factor for fatigue, N/m^2
$Q = 2N_g/(N_p + N_g)$
N_g= number of teeth on gear
N_p= number of teeth on pinion

and
$$K = \frac{s_{es}^2 (\sin\phi)(1/E_p + 1/E_g)}{1.4}$$

Where, s_{es} = surface endurance limit of a gear pair, N/m^2
E_p = modulus of elasticity of the pinion material, N/m^2
E_g = modulus of elasticity of the gear material, N/m^2
ϕ = pressure angle.

The surface endurance limit may be estimated from,
$$s_{es} = (2.75\ (\text{BHN}) - 70)\ \text{MN/m}^2$$

where, BHN may be approximated by the average Brinell hardness number of the gear and pinion up to a BHN of about 350 for steels.

The wear load F_w is an allowable load and must be greater than the dynamic load F_d.

Values of Deformation Factor **C** in kN/m – for dynamic load check.

Materials		**Involute tooth form**	**Tooth Error - mm**				
Pinion	Gear		0.01	0.02	0.04	0.06	0.08
cast iron	cast iron	14 ½ °	55	110	220	330	440
steel	cast iron	14 ½ °	76	152	304	456	608
steel	steel	14 ½ °	110	220	440	660	880
cast iron	cast iron	20 ° full depth	57	114	228	342	456
steel	cast iron	20 ° full depth	79	158	316	474	632
steel	steel	20 ° full depth	114	228	456	684	912
cast iron	cast iron	20 ° stub	59	118	236	354	472
steel	cast iron	20 ° stub	81	162	324	486	648
steel	steel	20 ° stub	119	238	476	714	952

Values for S_{es} as used in the wear load equation depend upon a combination of the gear and pinion materials. Some values for various materials for both S_{es} and k are tabulated.

Average Brinell Hardness Number of steel pinion and steel gear		**Surface Endurance Limit** S_{es} (MN/m^2)	**Stress Fatigue Factor K (kN/m^2)**	
			14 ½ °	**20°**
150		342	206	282
200		480	405	555
250		618	673	919
300		755	1004	1372
400		1030	1869	2553
Brinnel Hardness Number BHN				
Steel Pinion	Gear			
150	C.I.	342	303	414
200	C.I.	480	600	820
250	C.I.	618	1000	1310
150	Phosphor Bronze	342	317	427
200	Phosphor Bronze	445	503	689
C.I. Pinion	C.I. Gear	549	1050	1420
C.I. Pinion	C.I. Gear	618	1330	1960

Form Factors y – for use in Lewis Strength Equation (transformed). $F = s\pi^2 kym^2$ is given in the following table:

Number of Teeth	14 ½° Full-Depth Involute of Composite	20° Full-Depth Involute	20° Stub Involute
12	0.067	0.078	0.099
13	0.071	0.083	1.103
14	0.075	0.088	0.108
15	0.078	0.092	0.111
16	0.081	0.094	0.115
17	0.084	0.096	0.117
18	0.086	0.098	0.120
19	0.088	0.100	0.123
20	0.090	0.102	0.125
21	0.092	0.104	0.127
23	0.094	0.106	0.130
25	0.097	0.108	0.133
27	0.099	0.111	0.136
30	0.101	0.114	0.139
34	0.104	0.118	0.142
38	0.106	0.122	0.145
43	0.108	0.126	0.147
50	0.110	0.130	0.151
60	0.113	0.134	0.154
75	0.115	0.138	0.158
100	0.117	0.142	0.161
150	0.119	0.146	0.165
300	0.122	0.150	0.170
Rack	0.124	0.154	0.175