Design and Manufacture of a Ten Ton Capacity Wedge Jack

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ABTRACT

A Wedge Jack of relatively small dimensions (300 x 100 x 50 mm), but extremely high load carrying capacity (10 tons) has been designed for precision lifting of turbine shaft and its bearing cases for their proper allignment at Ghorasal Power Plant. The work was unique of its kind in Bangladesh, since it was the first venture of installation of a new power plant using local technology and expertise. The Jack was a key inventory item, without which the erection work was not technologically feasible. Its import from abroad or local manufacture using foreign expertise would involve huge cost and delay in the erection. Design of the same by an expert team of B. U. E. T. has solved the above mentioned problem. The designed Wedge Jack consists of an upper plate, a lower plate, two wedges and threaded shaft. Rotation of the shaft in one direction facilitates lifting up of the upper plate along with the given load, while rotation in the opposite direction lowering down of the same. Safety factors in the range from 1.5 to 3.5 for various parts of the Jack have been ensured by the design. For ease of production a few sample pieces of the same were manufactured under the supervision of the designers. The manufactured Wedge Jacks were tested for accuracy and the required load carrying capacity.

Introduction

The offer for designing the Wedge Jack came from the Power Development Board (PDB) of Bangladesh. The Jack was urgently needed at the Ghorasal Power Plant (GPP) for precision installation of heavy turbine parts, weighing upto 10 tons. Dimension of the Wedge Jack, required was approximately 300 x 100 x 50 mm, which may be considered not large. Such a problem was faced for the first time in the country, since the installation of the power plant was intended to be done using local technology. It is quite obvious that the accuracy of installation the turbine parts was very much essential for proper functioning of the whole plant. That is why a precision type wedge jack was essential for the installation to go on. The problem would not arise if the

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plant would be supplied with the required Wedge Jacks by the supplier of the plant (USSR). In the absence of the specified Jacks the authorities of GPP were left with two options before them. First, to seek help from any foreign organization to design and manufacture the Wedge Jack. But this would have undoubtedly cost very high and the installation would be delayed. Second, to try manufacture the same within the country. GPP was bold enough to go for the second option. It undoubtedly involved little bit of risk and uncertainty as to whether such an important part could be designed and manufactured properly inside the country. The expert consultancy services of BUET were rightly sought for the above mentioned job. The Department of Industrial & Production Engineering takes pride not only in designing the complex type of Wedge Jack required for the purpose but also in supervising the manufacture of few sample pieces in the Machine shop of BUET.

Criticality of the Product Design

As mentioned above the Wedge Jack was intended to carry heavy loads (upto 10 tons). This loading capacity for the required dimensions (300 x 100 x 50 mm) asked for careful selection of materials for its manufacture specially when scarecity of materials prevails in the country. Secondly, the restriction of all movements of the upper plate except its vertical movement, requied for undisturbed lifting of the turbine parts, made the job more complicated. Thirdly, the limitations of the available technology and know how for the manufacture of such a critical part had to be taken into consideration while designing the product.

Detail of the Design

The main parts of the Wedge Jack are:

1. Rotating shaft
2. Upper plate
3. Lower plate
4. Right hand Wedge
5. Left hand Wedge

In actual operation the Wedges should slide axially along the dovetail type slide ways of the lower plate upon rotation of the shaft and lift vertically up the upper plate carrying the load upto a height of 8 ± 0.5 mm. Since the upper plate should not have any movement except in the vertical direction all degrees of freedom of the wedges excepting their motion in the axial (longitudinal) direction were needed to be restricted. This called for dovetail type slide ways in the lower plate and adjustment of all clearances between the mating surfaces of the guiding & guided slide ways by means of parallel adjustable strips. All the degrees of freedom of the upper plate apart from its motion in vertical direction was restricted by choosing prismatic type slide ways in between the upper plate and the wedges. Restriction of motion in the lateral direction was ensured by keeping provisions for adjustment of clearances between the mating surfaces of the shoft ways. Restriction of motion in the longitudinal directions was ensured by means of a circular slot in lower surface of the upper plate which registers against the shoulder in the middle of the shaft. In this arrangement all the three rotational motions of the upper plate are also restricted (Fig. 1).

The longitudinal movement of the wedges is restricted corresponding to the highest position of the upper plate by means of a cross plate fixed in the middle of the lower plate. Corresponding to the lowest position of the

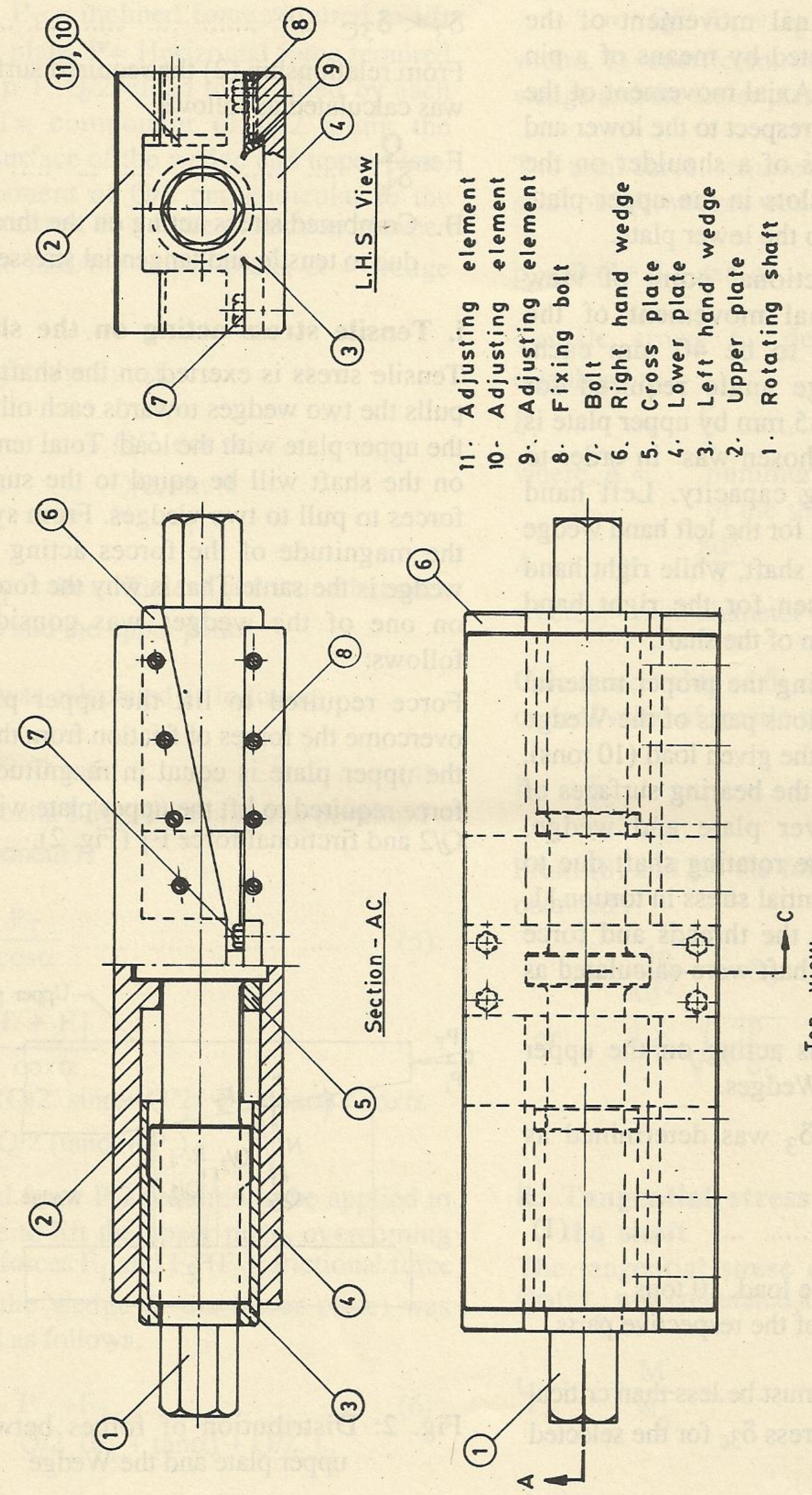

FIG 1. ASSEMBLY OF WEDGE JACK

upper plate longitudinal movement of the Wedge may be restricted by means of a pin fixed inside the shaft. Axial movement of the shaft is restricted with respect to the lower and upper plates by means of a shoulder on the shaft, corresponding slots in the upper plate and cross plate, fixed to the lower plate.

From design/constructional point of view maximum longitudinal movement of the Wedges was chosen to be 40 mm each. Corresponding Wedge angle required for vertical travel of 8 $\pm$ 0.5 mm by upper plate is 12°. Type of thread chosen was in order to raise its load bearing capacity. Left hand square thread is chosen for the left hand wedge and left portion of the shaft, while right hand square thread is chosen for the right hand wedge and right portion of the shaft.

With a view to selecting the proper material and dimensions of various parts of the Wedge Jack corresponding to the given load (10 tons), compressive stress of the bearing surfaces of the upper plate, lower plate and wedge, combined stress on the rotating shaft due to tensile stress and tangential stress in tortion [1, 2], shearing stress on the threads and force required to rotate the shaft were calculated as follows:

A. Compressive stress acting on the upper plate, lower plate and Wedges.

Compressive stress, δ_3 was determined as follows:

$$\delta_3 = \frac{Q}{F} \quad \ldots \quad (1)$$

where, Q - Compressive load, 10 tons
F-Surface area of the respective parts.

Calculated value of δ_3 must be less than critical value of compressive stress δ_{3c} for the selected material,

$$\delta_3 < \delta_{3C} \quad \ldots \quad (2)$$

From relationship (2) the required surface area was calculated as follows:

$$F > \frac{Q}{\delta_{3c}} \quad \ldots \quad (3)$$

B. Combined stress acting on the thread shaft due to tensile and tangential stresses

i. Tensile stress acting on the shaft

Tensile stress is exerted on the shaft when it pulls the two wedges towards each other to lift the upper plate with the load. Total tensile load on the shaft will be equal to the sum of the forces to pull to two wedges. From symmetry the magnitude of the forces acting on each wedge is the same.That is why the force acting on one of the wedges was considered as follows:

Force required to lift the upper plate and overcome the forces of friction from the side of the upper plate is equal in magnitude to the force required to lift the upper plate with a load Q/2 and firctional force F_1 (Fig. 2).

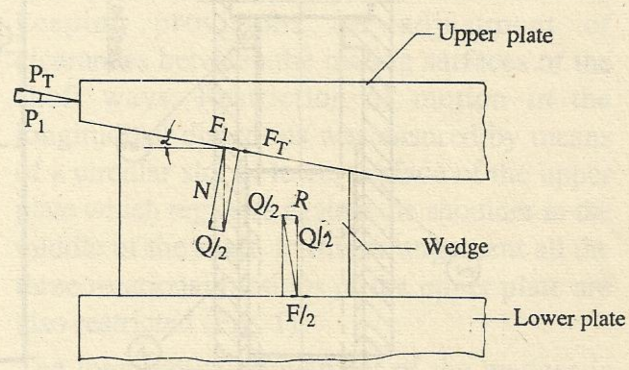

Fig. 2: Distribution of forces between the upper plate and the Wedge

In Fig. 2, P_T = inclined force required to lift the upper plate, P'= Horizontal force required to develop T, Q/2= load to be lifted by each wedge, T= component of Q/2 along the inclined surface of the wedge and upper plate, N= component of Q/2 perpendicular to the inclined surface, F_1= force of friction between the wedge and the upper plate, α = wedge angle.

According to the figure,

$$N = Q/2, \cos\alpha$$
$$T = Q/2, \sin\alpha$$
$$F_1 = N.\ f_1$$

where, f_1 is the cofficient of friction between the wedge and the upper plate.

Force P_T was calculated as follows:

$$P_T = T + F_1 \quad \dots \quad (4)$$

The horizontal force, P' required to develop P_T as a component is

$$P' = \frac{P_T}{\cos\alpha} \quad \dots \quad (5)$$

$$= \frac{T + F_1}{\cos\alpha}$$

$$= (Q/2.\ \sin\alpha + Q/2.\ P_1.\ \cos\alpha) / \cos\alpha$$

$$= Q/2\ (\tan\alpha + P_1)$$

Horizontal force P/2 required to be applied to the wedge to lift the upper plate, overcoming frictional forces F_1 and F_2 (F_2= frictional force between the wedge & the lower plate) was calculated as follows.

$$P/2 = P' + F_2 \quad \dots \quad (6)$$
$$= Q/2\ (P_1 + \tan\alpha) + Q/2.\ f_2$$
$$= Q/2\ (P_1 + f_2 + \tan\alpha)$$

where, f_2- coefficient of friction between the wedge and the lower plate

The total force, required to be exerted by the shaft on the wedges was calculated as follows:

$$p = Q\ (1 + 2 + \tan\alpha \quad \dots \quad (7)$$

Tensilc stress δ_1 developed, was then calculated as

$$\delta_1 = \frac{P}{A} \quad \dots \quad (8)$$

where, A = minimum cross sectional area of the shaft.

$$A = \frac{\pi d^2}{4},$$

where d= min. diameter of the threaded shaft.

Calculated value of δ_1 should be less than the critical value of tensile stress, δ_c.

$$\delta_1 < \delta_c \quad \dots \quad (9)$$

From (8) and (9) the following relationship is obtained :

$$\frac{4p}{\pi d^2} \leq \delta_c$$

or $$d \geq \sqrt{\frac{4p}{\pi\ \delta_c}} \quad \dots \quad 10)$$

ii. Tangential stress due to tortion on the shaft

The tangential strese due to tortion on the shaft t_T was caleutated as follows:

$$t_T = \frac{M}{w_p} \quad \dots \quad (11)$$

where, M = Torque developed due to rotation of the shaft.

w_p = Moment of resistance = $0.2 \times d^3$

M was determined as follows:

$$M = P f_3 \frac{d}{2}$$

where, f_3 = coefficient of friction between the external thread of the shaft and internal thread of the wedges.

Putting the value of w_p and M in equation (11),

$$T = \frac{p\ f_3 d}{2 \times 0.2\ d^3}$$

$$= \frac{p\ f_3}{0.4\ d^2}$$

But $t_T < t_c$ .... (12)

where, t_c = critical value of tangential stress.

so from (12)

$$d > \frac{p\ f_3}{0.4\ t_c} \quad \text{...... ....} \quad (13)$$

For final selection of d, the larger of the two values as calculated from equation (10) and (13) was accepted.

iii. Combined stress on the shaft

Combined stress due to tensile & tangential stress is given by

$$\delta_{com} = \frac{\delta_1}{2} + \sqrt{\left(\frac{\delta_1}{2}\right)^2 + t_1^{\ 2}} \quad \text{.....} \quad (14)$$

The calculated value of $\delta_{com} < \delta_{cc}$

where δ_{cc} is the critical value of the comibned stress.

C. shear stress acting on the thread

shear stress t_s was calculated as

$$t_s = \frac{p}{A'} \quad \text{...... ....} \quad (15)$$

where A' = Area of the thread surface under shear

$$A' = \frac{\pi dz}{\cos \beta}\ b \quad \text{.......... ....} \quad (16)$$

where z = Min. number of threads of the shaft in contact with those of the wedge

ß = Lead angle of the thread,

b = Width of each thread $\frac{s}{2}$, where s is the pitch of the square thread

$$\tan\beta = \frac{s}{\pi d} < f_3 \quad \text{.............. ......} \quad (17)$$

Putting the value of b and β in equation (16) and putting the values of A' in (15) the following may be written :

$$t_s = \frac{2p \times \cos \text{arc} \tan \frac{s}{\pi d}}{\pi dzs} \quad \text{... ....} \quad (18)$$

But $t_s < t_{sc}$ .... (19)

where t_{sc} = critical value of shear stress.

Having selected the diameter, and knowing t_{sc}, p, t (from inequality 17), z may be calculated as per relationship (19)

For maintaining size of the Wedge Jack within the specified limited dimension, (300 x 100 x 50) the material of various parts of the Jack is selected in conjunction with the calculated values of the parameters in sections (A), (B) and (C), ensuring safety factor in the limit from 1.5 to 3.5 for the various parts. The selected material is ST40, having the following specifications :

Composition :	C	=	0.35 - 0.45%
	Si	=	0.30 - 0.35%
	Mn	=	0.60 - 0.90%
	S	=	Max. 0.05%
	P	=	Max. 0.05%
Tensile strength		=	58-68 kg/mm^2

Conclusion:

A few samples of the designed Wedge Jack were manufactured in Bangladesh University of Engineering & Technology under the supervision of the designers. The rest of the pieces were manufactured in different places. The cost for manufacturing these Wedge Jacks using local materials and technology was a few times less than the imported cost and all the pieces worked successfully for precision lifting of the turbine shafts and their I bearing cases for their proper allignment at Ghorasal Power Plant.

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