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Research on Determining the Torque Bearing Capacity of Clamp and Cap Assemblies

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Abstract

The paper presents theoretical and experimental research on the clamp and cap assemblies. Particularly, it inquires into the determination of the torque bearing capacity. It applies the main analytical calculus procedures of dependence to the screwing up load and torque bearing capacity of the assembly.
By using a specific assembly model and a specialised torsion stand it is possible to verify the analytical calculus results experimentally.

Key words: *assembly, screwing up load, clamp and cap assembly, torque bearing capacity.*

Theoretical considerations

The clamp and cap assemblies are restricted in use to special cases of low torque loading, frequent mounting-dismounting jobs, tightening adjusting needs or maintenance of critical shaft section [1], [4], [5], [7].

Frequently, these assemblies are used to join specific parts as bar, stem, verge, axle or shaft and different exterior component such as crank, lever or a kind of transmission gear, which are usually joined together by the clamp.

The clamp and cap assembly is a specific type of general category of tightening clamp assemblies that can be classified according to the following criteria [2], [5]:

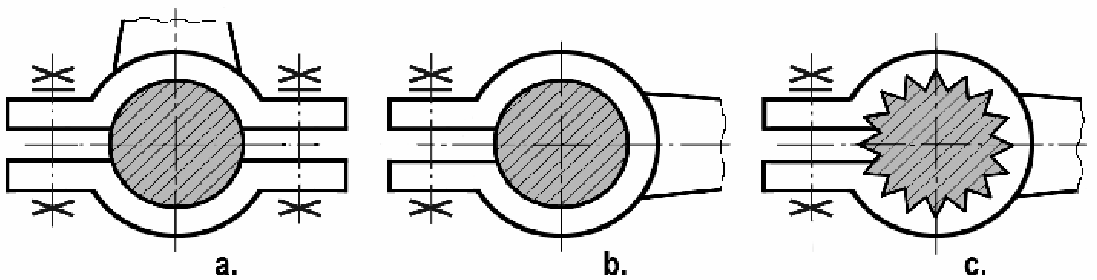

Fig. 1. Tightening clamp assemblies: *a* – clamp and cap assembly; *b* – sectional clamp assembly; *c* – sectional denticulate mating surface assembly

- Clamp shape:
  - clamp and cap assembly (fig. 1, *a*);
  - sectional clamp assembly (fig. 1, *b*, *c*);
- Contact shaft-clamp shape:
  - smooth (flatten) surface (fig. 1, *a*, *b*);
  - denticulate surface (fig. 1, *c*).

The working operation of this kind of assemblies is based of frictional forces developed between the joint elements as a result of typical forces acting onto mating surfaces.

Considerations over analytical calculus of clamp and cap assembly

The calculus scheme and the main components of the clamp and cap assembly are depicted in figure 2.
The working shaft (1) squeeze is made by the clamp (2) and cap (3) when threaded pair bolt-nut (3-4) are screwed up.

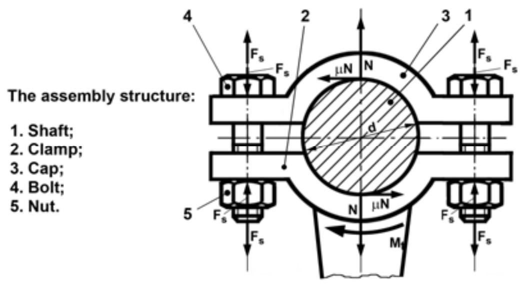

Fig. 2. The clamp and cap assembly: structure and calculus scheme

In this tightening conditions, when torque moment, M_t, is applied on shaft, it can be transferred to clamp-cap component if the F_s axial force is developed in the bolt pair. The squeezing force generated by clamp-cap over the shaft can be expressed by writing down the frictional torque condition [2], [3], [5]:

$$M_f = \mu_c \cdot N \cdot d = c_s \cdot M_t \,, \tag{1}$$

where:
- μ_c is the friction coefficient on the component cylinder mating surface;
- c_s – the safety coefficient.

Using relation (1) we can write the thrust force of the clamp pushing on the shaft:

$$N = \frac{c_s \cdot M_t}{\mu_c \cdot d} \,. \tag{1′}$$

Writing down the equilibrium condition of the clamp (fig. 2):

$$N - 2 \cdot z \cdot F_s = 0 \,, \tag{2}$$

if z is the number of threaded connections on each clamp side, the squeezing F_s axial force becomes:

$$F_s = \frac{N}{2z} \,. \tag{2′}$$

If considering also equation (1′), the final relation for the axial load will be:

$$F_s = \frac{c_s \cdot M_t}{2\mu_c \cdot z \cdot d} \,. \tag{2″}$$

The experimental system and the instrumentation used

In order to confirm the analytical calculus, the special installation for clamp assemblies testing was designed in the Machine Elements Laboratory of Petroleum-Gas University of Ploiesti [2]. This installation can be used for experiments concerning various assembly types [6] such as the sectional clamp model. The structure of the testing installation is composed by the following parts:

- Clamp and cap assembly (fig. 3);
- Special stand for assembly twisting tests;
- Specific instrumentation (dynamometer, torque wrench, slide calliper rule, etc.).

The special installation for experimental testing is presented in the figure below.

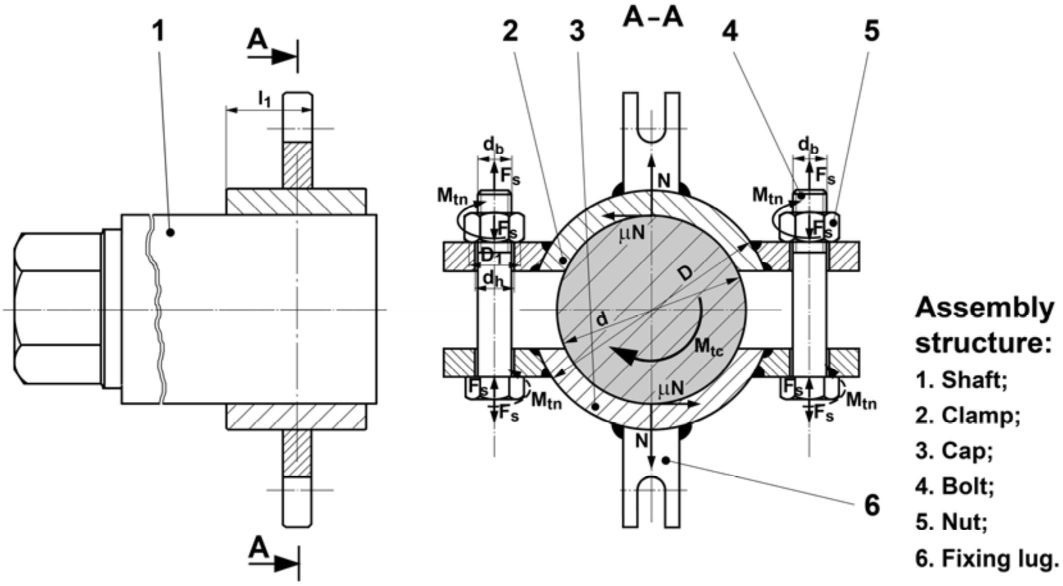

Fig. 3. Experimental installation which represents the designed clamp and cap assembly

The sectional clamping assembly is composed of shaft 1 with an end finished with a cylinder surface and the other end with a portion having hexagonal outline. The latter is required in order to mount the assembly into the twisting test device. The essential part is composed of tightening sectional clamp 2 and similar cap 3 (both made into welded design form with a fixing lug shape 6) and the squeezing threaded pair of elements, bolt 4 and nut 5.

The axial tightening force F_s, applied in order to transmit the M_t torque, can be reached by screwing nut 5 by the torque wrench. The torque applied is read on the scale of the torque wrench (controlled torque M_{tm}).

For the purpose of the analytical calculus the friction feature for the friction surfaces needs to be determined. For part assembling surfaces (shaft-clamp-cap) – achieved by fine turning – the following intervals may be considered for the values of friction coefficients:

- For the thread friction surfaces (bolt and nut threaded surfaces):
  μ = 0.10...0.15; the recommended value is μ = 0.12
- For the nuts positioning surface:
  μ_r = 0.10...0.12; the recommended value is μ_r = 0.11
- For shaft-clamp-cap mating cylinder surface:
  μ_c = 0.05...0.10; the recommended value is μ_c = 0.08.

The determination of load characteristics for clamp and cap assembly

When tightening the nut pair 5 by the means of the torque wrench into the threaded rod, an initial tightening force develops ($F_o = F_s$). It stretches the screw type part (4) and compresses the flange type parts (clamp 2 and cap 3).

Depending on the value of the torque applied with the torque wrench, M_{tn} – which has equalization in view –the initial tightening force F_o can be expressed as follows:

$$F_o = \frac{M_{tn}}{\frac{d_2}{2} \cdot \text{tg}\,(\alpha_m + \varphi') + \frac{1}{3} \cdot \mu_r \cdot D_r} = k_1 \cdot M_{tn} = F_s \,. \tag{3}$$

In formula (3) all components have familiar meaning: d_2 is the thread average diameter for the bolt and the nut, α_m is the average thread evolute's gradient, φ' is the reported friction angle and D_r is the reported diameter of the nut positioning surfaces. The mentioned expression can be expressed in a condensed form by using factor k_1, which includes mentioned constants for the chosen threaded elements size.

The reported friction angle φ'can be expressed in the following formula:

$$\text{tg}\,\varphi' = \frac{\mu}{\cos\frac{\beta}{2}} \,, \tag{4}$$

where μ is the used thread friction factor of the bolt-nut surfaces and β is the thread generator profile angle.

Regarding the reported diameter of nut positioning surfaces, we can calculate it by formula:

$$D_r = \frac{D_1^3 - d_h^3}{D_1^2 - d_h^2} \,, \tag{5}$$

with D_1 and d_h well-known geometric parameters.

When equation (2) is applied using the notation $k_2 = 2z$, the thrust force expression for the clamp-cap pushing on the shaft on the cylindrical surface ensues:

$$N = 2z \cdot F_s = k_2 \cdot F_s \,. \tag{6}$$

The bearing torque capacity M_{tm} of the assembly may be expressed through the following relation:

$$M_{tm} = \mu_c \cdot N \cdot d = k_3 \cdot N \,, \tag{7}$$

where factor k_3, explicit in relation (7), is expressed in [mm].

The experimental procedure to determine the torque bearing capacity of the clamp and cap assembly

The experimental procedure to determine the torque bearing capacity of clamp and cap assembly is similar to the one described in a previous article [2] for sectional clamp assembly. The experimental technique uses a special torsion stand (on which also other types of detachable assembly types can be tested) and is detailed in figure 4 [6].

The torque loading of the assembly is applied by the means of a motion screw acting on a lever of length R. The axial force developed in the motion screw (F) is monitored by the means of a dynamometer resulting as follows:

$$M_{tm(exp)} = F \cdot R \cdot \eta_r \,, \tag{8}$$

where η_r means the mechanical efficiency of the whole mechanical system of levers and screw. The usual values can de considered in the interval η_r = 0,90…0,97.

The experimental determination of the torque bearing capacity for the clamp and cap assembly requires the following steps:

- The tightening of the nut of the assembly by applying the first level of torque (M_{tn}), with the same value at each nut. This value is read with the torque wrench. Depending on the value of the applied torque, the initial tightening force $F_o = F_s$ is determined – by applying relation (3), the typical response, N – relation (6) and the ultimate theoretical torque of the assembly, M_{tm} – relation (7).
- The clamp and cap assembly is mounted on the stand and stressed to torsion while reading with the dynamometer the value of the force (F) developed in the motion screw corresponding to the wheel of the shaft 1 versus the clamp and cap 2-3. In this way, the level of the experimental torque bearing capacity $M_{tm(exp)}$ results using relation (8). This time, the ultimate torque determined analytically, M_{tm}, can be compared with the one deducted experimentally, $M_{tm(exp)}$.
- Afterwards, same experimental stages are repeated several times, for increasing values of the nut screwing moment.

All theoretical and experimental results have to be gather up (table 1) by the purpose of graphical subsequent transposing (Fig. 5).

Table 1. The synthesis of the characteristic values determined analytically and experimentally

No.	M_{tn}, [Nm]	μ	μ_c	μ_r	α_m, [°]	φ', [°]	d, [mm]	k_1, [mm^{-1}]	F_o (F_s), [N]	k_2	N, [kN]	k_3, [mm]	M_{tm}, [Nm]	R, [m]	F, [N]	$M_{tm(exp)}$, [Nm]
1	40														F_1	$M_{tm(exp)1}$
2	60														F_2	$M_{tm(exp)2}$
3	80														F_3	$M_{tm(exp)3}$

Using some of characteristics presented above, it is possible to draw graphics depicting F_o and M_{tn} interdependence and also M_{tm} and $M_{tm(exp)}$ dependent on M_{tn} (fig. 5).

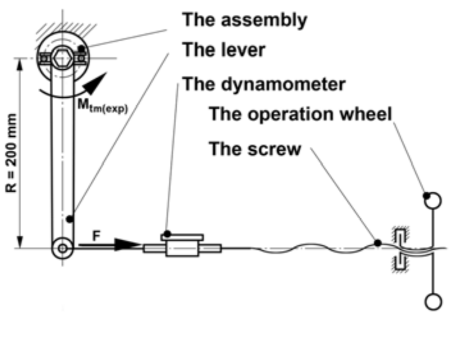

Fig. 4. Stand kinematical scheme

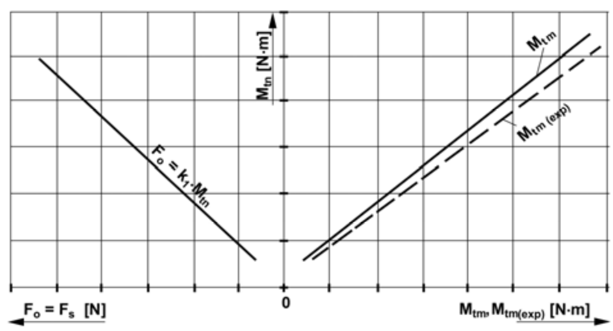

Fig. 5. Synthetic graphics of analytical and experimental results

Conclusion

On the basis of analytical methodology proposed, as well as on experimental results of the clamp and cap assembly tests, there are some significant conclusions to be drawn:

- Using the theoretical algorithm, the linear dependence between screwing up torque (M_{tn}) and tightening forces (F_s and N) developed in threaded elements is relevant.
- At the same time, the deduced function between the tightening torque and torsion bearing capacity shows a similar linear-increasing aspect.
- Most of the preliminary experiments developed using the clamp and cap assembly present a relative closeness between the experimental results ($M_{tm(exp)}$) and the calculated ones (M_{tm}) at all loading levels. At higher tightening levels, the result approaching is obvious.
- Some of the differences recorded between calculated and experimental values of the torque may be accounted for by various causes: errors in reading of the nut screwing moment, errors in reading force on dynamometer and differences between values of actual friction coefficients versus the estimated (selected for calculation) ones.
- Experiments depict the importance of the torque (M_{tn}) and the load (F_s) equalization on each z threaded element of the clamp-cap assembly. This specific aspect suggests that research should be extended to include the influence of applying the tightening torque to the bearing capacity of the joint.

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Asupra determinării capacității portante a asamblării cu brățară şi capac

Rezumat

Lucrarea prezintă cercetări teoretice şi determinările experimentale aferente determinării capacității portante a asamblărilor cu brățară de strângere şi capac. În cadrul lucrării sunt prezentate procedurile de calcul analitic privind dependența dintre forța axială de strângere a asamblării şi momentul de torsiune capabil al acesteia. Prin folosirea unui model şi a standului specializat dedicat încercărilor la torsiune au putut fi verificate experimental aceste rezultate obținute pe cale analitică.