MECHANICAL DESIGN OF NIS NEW REFERENCE TORQUE STANDARD MACHINE

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ABSTRACT - Standard torque measuring machines and their traceability is relatively new in metrology field. The growing car manufacturing and assembly industry in Egypt made it necessary to develop a national standard for torque measurement which can provide traceability to the industry according to world wide standards. A new design of 3 kNm reference torque standard machine was therefore considered. The machine was designed following the component system principle based on the vertical axis measurement method, without intermediate bearing, which reduces about 70% of the cost. Prior to that, the parts chosen for the design as well as the machine structural parts are reviewed. Stresses in the critical parts of the machine are computed using Finite Element (FE) analysis to ensure that the designed machine can satisfy the International requirements.

Keywords: torque, torque standard machine, traceability

1. Introduction

It is wise to say that torque is not simply force multiplied by length; this statement is the real start in metrology to deal correctly with torque measurements and calibrations. Standard torque measuring equipment traceability was first set in early 1990ˢ [1]. On one hand, force and length measurements are two fields of metrology; each of them has its own problems, and difficulties. On the other hand, when they combine in torque measurements, new problems and difficulties will arise. Measuring systems are usually designed for sensing certain quantity under the prerequisite minimization of the effects of disturbing quantities. This ensures achieving the nearest possible actual value for the desired quantity. In the present design, the moment (pure torque) is the desired quantity, and the disturbing quantities are the bending moment, and the axial force. The measurement / calibration facility should be designed in such way to guarantee minimum disturbance to the sensing element. Therefore, the designer should recognize the disturbing quantities and know their sources and their expected effects before working for reducing or even eliminating them. In addition, the torque transducer should be selected so as to compensate the effects of such disturbing quantities [2]. In the design procedure of the calibration facility described below two basic designs employing comparison procedure were found. These are machines with horizontal axis [2] and others with vertical axis [3, 4, 5]. The important merits of vertical axis are avoiding using expensive air bearing and reducing the number of flexible couplings. It needs only two flexible couplings as compared with four in case of machines employing comparison procedure with horizontal axis.

2. Three kNm Torque Standard Machine

In 1996, Peschel [6] proposed a modular design for a torque standard horizontal axis machine on the basis of commercial components. In 2004, Aggag discussed with Peschel [5] the possibility for applying his proposed modular design in vertical axis. According to this discussion, three kNm torque standard machine has been designed for a measuring range between 5 Nm and 3 kNm (fig.1). Some investigations were carried out for measuring range between 0.1Nm and 10 Nm by adding two small flexible couplings between the two transducers. Therefore, interchangeable reference torque transducers with similar dimensions of the fitting parts are used.
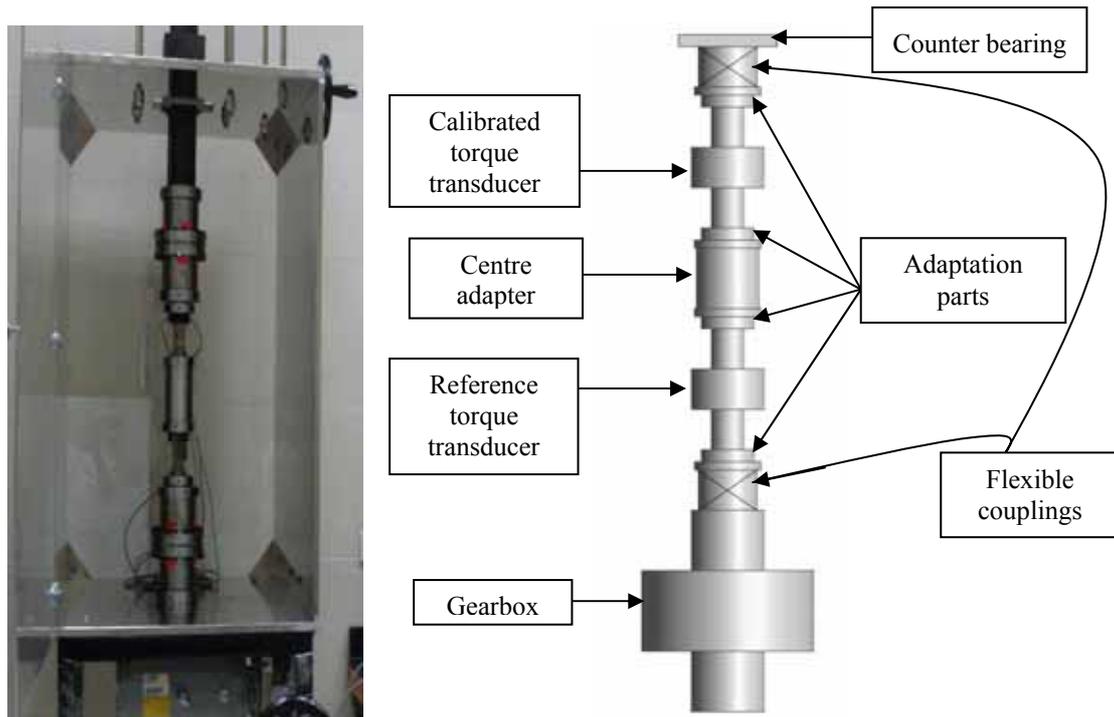
Fig. 1: Main components of 3 kNm Torque standard machine (5 Nm up to 3 kNm).

3. Design concept

The torque of this machine is applied throw worm gearbox (i=3200) that is transmitted to both reference and calibrated torque transducers throw hydraulic clamps. The flexible couplings used in the system to avoid misalignment were torsionally stiff to compensate bending moment up to certain limit.
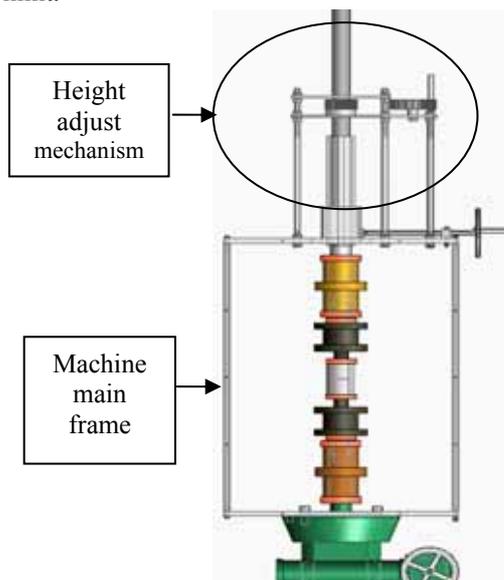

Fig. 2: Machine main frame and height adjustment mechanism together with the basic standard components.

A height adjusting mechanism (fig. 2) was used for adjusting machine height to fit various types of transducers, and also to function as a counter bearing to the reaction torque on the machine frame.

Figure 2 show the two basic designed components; machine main frame and height adjustment mechanism together with the basic standard components.

3.1. Design of machine main frame

The main frame of the machine was designed to be rigid enough to sustain the maximum capacity of 3 kNm torque and to be easy enough for machine setup. Three alternative designs (fig. 3 a, b and c) for the frame were considered;

a) Two plates and four tie rods.
b) Rectangular box.
c) Cylinder [3].

Finite Element analysis using ABACQUS software was applied to determine stresses and deflection in the three alternative designs; and the corresponding deformation under the same torque and element size were compared as follows;
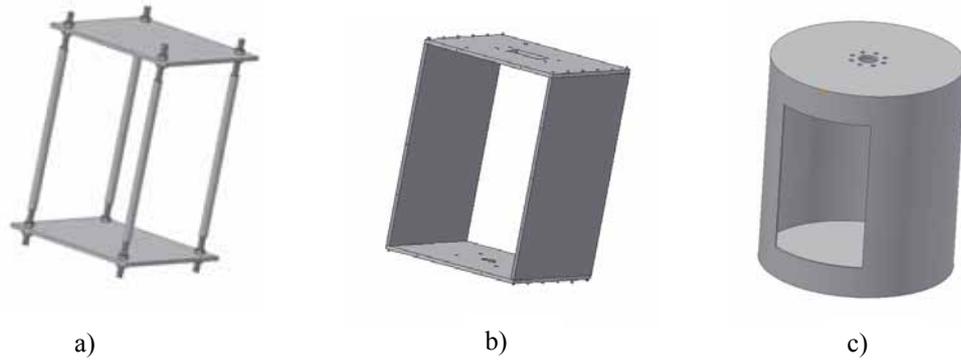
a)   b)   c)

Fig. 3: Alternative designs for main frame of torque machine.

a- Two plates of 20 mm plate thickness and four tie rods of 60 mm diameter made from steel 37 were considered. Shown in figures 4 and 5, is the FE results which indicate that the maximum stress is 28.2×10^6 N/m^2 with 1.36 cm horizontal deflection.

75690 Tet elements

Fig. 6: Finite Element analysis for rectangular box design (8.3 MPa maximum stress).

57516 Tet elements

Fig. 4: Finite Element analysis for two plates and four tie rods design (28.2 MPa maximum stress).

Fig. 7: Finite Element analysis for rectangular box design with 0.022 cm maximum deflection.

c- Cylinder of 20 mm, wall thickness and 20 mm , made from steel 37. Shown in figures 8 and 9, are the FE results indicating maximum stress of 8.8×10^6 N/m^2 with 0.011 cm tangential displacement.
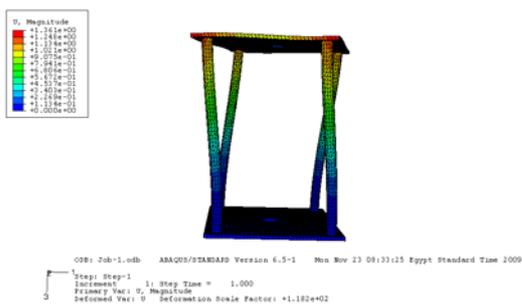

Fig. 5: Finite Element analysis for two plates and four tie rods design (1.36 cm maximum deflection).

b- Rectangular box made of steel 37 of 20 mm plates thickness. Shown in figures 6 and 7, are the FE results which indicate that the maximum stress is 8.3×10^6 N/m^2 with 0.022 cm horizontal deflection.
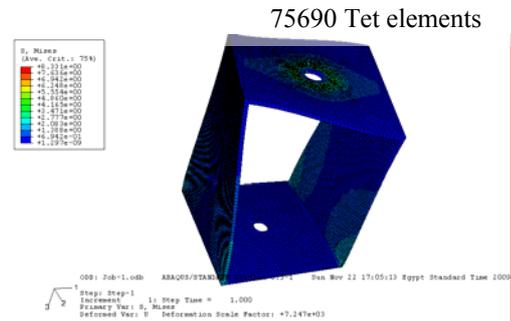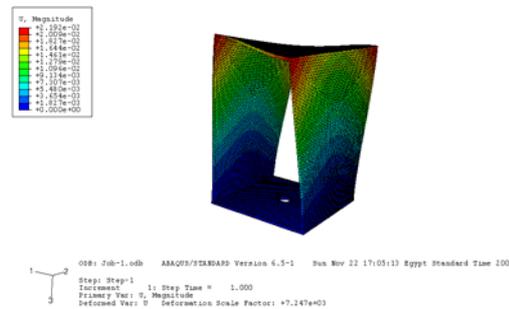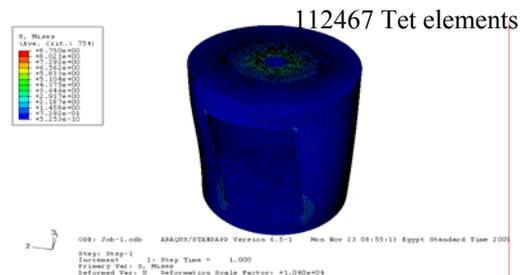
112467 Tet elements

Fig. 8: Finite Element results for cylindrical design showing maximum stress of 8.8 MPa.
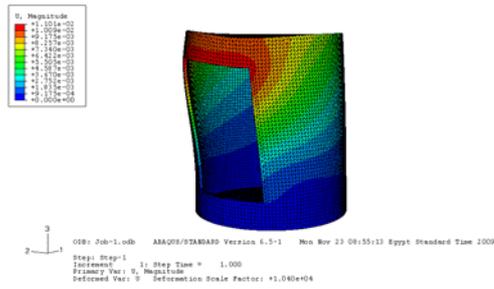
Fig. 9: Finite Element results for cylindrical design showing 0.011 cm maximum tangential displacement.

Comparing the resulting stresses and corresponding displacements for the three alternative designs (table 1), indicate that for same wall thickness, the rectangular box design is more suitable for its torsional stiffness, and simplicity in manufacturing. It also proved more suitable for accommodating transducers as compared with the cylindrical design. Although the two plates and four tie rods design also appeared to enjoy the simplicity of manufacturing, but the box design was selected, for its higher torsional stiffness, and relatively small angel of twist under torque as compared with the other designs.

Table 1: Results of Finite Element analysis for the 3 alternative main frame designs.

Design type	Max. stress (MPa)	Resulted deformation (cm)
Two plates and four tie rods	28.2	1.36
Rectangular box	8.3	0.02
Cylinder	8.8	0.011

A study of the torque transducer (capacity from 0.1 Nm up to 3 kNm) dimensions was carried out for the four most popular torque transducer's to determine the height of the rectangular box. This study shows that the maximum length without shafts of the torque transducers is 166 mm, whilst the minimum length is 65.5 mm. Therefore, the machine main frame is made using two square steel plates, 800x800x20 mm, as upper and lower plates and two other steel plates, 1200x800x20 mm, as side plates. This type of structure showed high torsional stiffness and its dimensions were suitable for calibration of all torque transducers within range from 0.1

Nm up to 3 kNm.The steel 37 frame was electroplated with nickel to resist corrosion. Figure 10 shows assembly drawing for the new design.
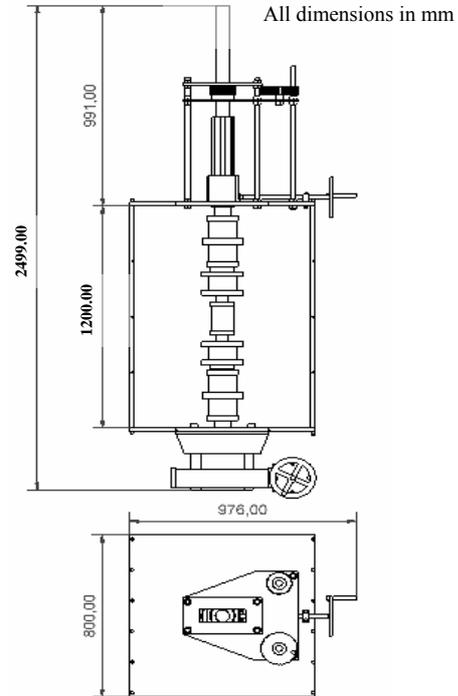

All dimensions in mm

Fig. 10: Assembly drawing for NIS 3kNm torque standard machine.

3.2. Height adjustment mechanism

The height adjustment mechanism (fig. 11) is designed for two purposes:

1-Adjust machine height according to the various heights of torque transducers and other related components.

2-Functioning as a counter bearing for reaction torque on the machine main frame. Therefore, the design (fig. 12) incorporated a spline shaft which divided into three parts;

a- Cylindrical part: whose dimensions are compatible with the hydraulic clamp for transmitting torque to spline shaft.

b- Spline shaft: for sliding inside a spline hub to adjust machine height. It is also used as a counter bearing for reaction torque on the machine main frame.

c- Threaded power screw and three timing pulleys, the middle one of them is threaded and placed between two plates which served as the nut. By rotating the master pulley, the belt transmits this rotation to the others. This implies that the spline shaft moves up or down depending on the direction of rotation of the master pulley.
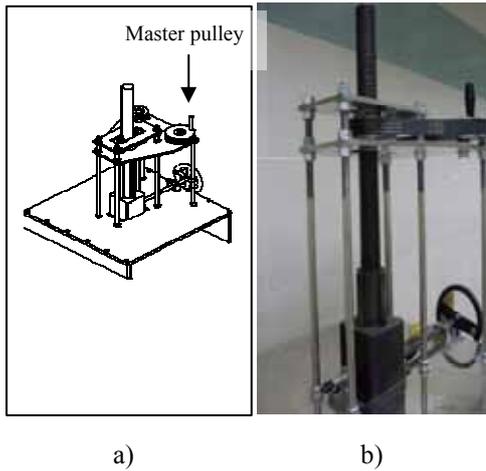
a)   b)

Fig. 11: Height adjustment mechanism
a) Schematic drawing and b) Photograph.

Therefore, the spline shaft and hub are designed to sustain 3 kNm torque and the FE analysis was used to check the resulting stresses.
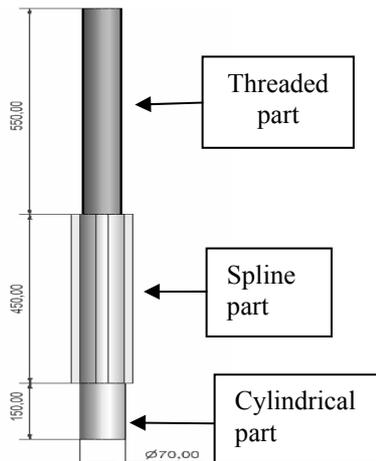

Fig. 12: Spline shaft's dimensions in mm.

3.2.1. Spline shaft and hub calculations

Figures 12 and 13 show the basic dimensions of the spline shaft and hub which must withstand the maximum torque defining the capacity of the machine (3 kNm).

The spline shaft and hub are made from BOHLR M238 steel, which has maximum tensile strength, $\delta_m = 1000 \times 10^6$ N/m^2 [7].

To determine the maximum torque this can be transmitted by the spline shaft. One can use the following equation [8];

$$M_t = phli(D-h)/2 \quad \ldots\ldots\ldots(1)$$

Where:
M_t is the transmitted torque.
p is the bearing pressure [8] = 13.7 MPa = 13.7×10^6 N/m^2
h is the spline height = (D – d)/2 = (96 – 72)/2 = 12 mm = 0.012 m.
D is the outer diameter = 96 mm = 0.096 m.
d is the inner diameter = 72 mm = 0.072m.
l is the spline hub length = 150 mm = 0.15 m.
i is the number of splines = 4.

M_t = (13.7 x 10^6 x 0.012 x 0.15 x 4 (0.096 – 0.012))/2.
$M_t = 4142$ Nm
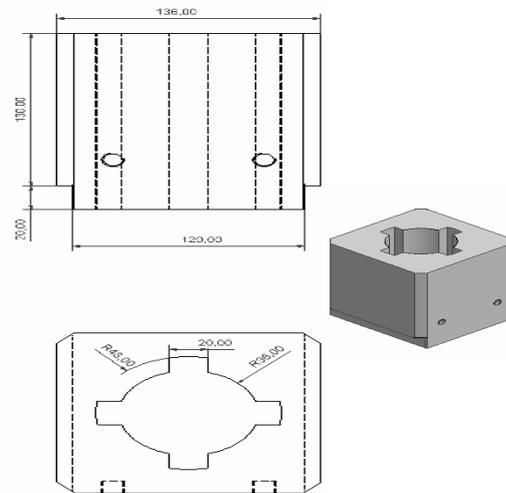The designed spline shaft can transmit torque exceeding 4.1 kNm.

Fig. 13: Spline hub basic dimensions in mm.

3.2.2. Spline shaft and spline hub finite element check

The spline shaft and spline hub stresses under load were checked using FE analysis. Tetragonal elements type was chosen to create the mesh design. Figure 14 and 15 shows the stress distribution under 3 kNm torque load in the spline shaft and spline hub respectively. The maximum stress in spline shaft is shown to be 104×10^6 N/m^2 whilst in the hub is 38.4×10^6 N/m^2.

This torsional load produces shear stress in the shaft, thereby causing one end of the shaft to twist relative to the other end [9].
The finite element analysis shows that the maximum shear stress in spline shaft is 104×10^6 N/m^2 and in spline hub 38.4×10^6 N/m^2. These values are lower than the allowable shear stress for the material used ($\tau = 330 \times 10^6$ N/m^2 [7]).

Using ABACQUS software the angel of twist for spline shaft was determined using the coordinates of a point in its outer surface before and after applying load. The maximum twist angle was calculated to be 0.0371° which is less than the permissible twisting angle for reference torque transducer (1°). Figure 16 show a photograph of the new machine after construction.
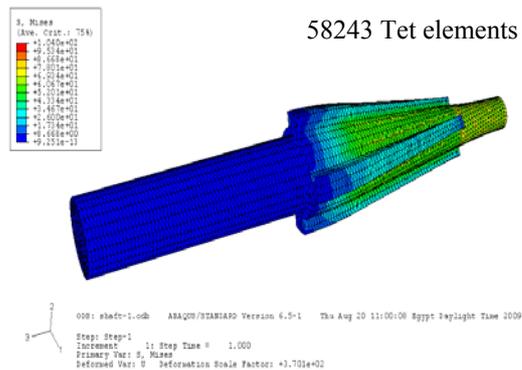

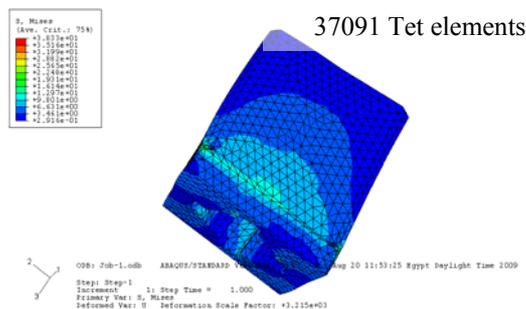Fig. 14: Finite Element analysis for spline shaft showing 104 MPa maximum stress.

Fig. 15: Finite Element analysis for spline hub showing 38.4 MPa maximum stress.

Fig. 16: A photograph for the constructed NIS 3 kNm torque standard machine.

4. Conclusion

Three kNm vertical reference torque standard machine was designed following modular component system. Rectangular box main frame was chosen for its high rigidity and small angle of twist (0.04º). The designed spline shaft can transmit torque exceeding 4.1 kNm. Finite Element (FE) analysis show that the maximum stresses occurred in critical parts is less than the allowable stresses.

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