

DESIGN OF THE 20 kN·m DEADWEIGHT TORQUE STANDARD MACHINE

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Abstract: This paper outlines a design of 20 kN·m deadweight torque standard machine to be commissioned by 2015 at KRISS. The torque machine incorporates newest technologies for user-friendliness and lower calibration uncertainties, such as an aerostatic bearing of double-cone type, a counter-drive with low backlash, and an individually controlled weighing system.

Keywords: torque, torque standard machine, calibration, deadweight.

1. INTRODUCTION

The KRISS (Korea Research Institute of Standards and Science) has decided to develop a 20 kN·m-capacity deadweight torque standard machine in response to the ever-growing demands for the traceable torque calibration from Korean heavy industries that need high-capacity torque measurements, such as turbines (wind or steam), motors (electrical and combustive) manufacturers. The machine is designed for generating traceable torques from 100 N·m to 22 kN·m with a target relative uncertainty of better than 5 parts in 10⁵. It weighs about 5 t without deadweights and has dimensions of approximately 3400 mm × 4400 mm × 3700 mm in width, depth, and height, respectively. The size in height includes a depth of underground pits accommodating weight stacks. Many recent techniques used for torque metrology will be adopted in the design. In this paper, we introduce the first design of the KRISS 20 kN·m torque machine shown in Fig. 1.

2. AIR-BEARING AND TORQUE ARM

A fulcrum plays a key role in transmitting torques generated by a multiplication of a lever-arm length and deadweights to the transducer without torque-loss due to friction. We chose an aerostatic bearing with double-cone shaped rotors (model XXL550, CEH Germany) as a fulcrum because it is designed to be able to support not only a radial load due to the weight of torque arm itself and weight stacks, but also bending moments and an axial force that could possibly arise from the weight of couplings, transducers and adapters during the calibration. According to specifications, this bearing can support a radial load up to 62 kN when each of air volumes flowing the upper and the lower parts of rotors is optimized. The capacities of the axial load and the bending moment are 15 kN and 2 kN·m, respectively.

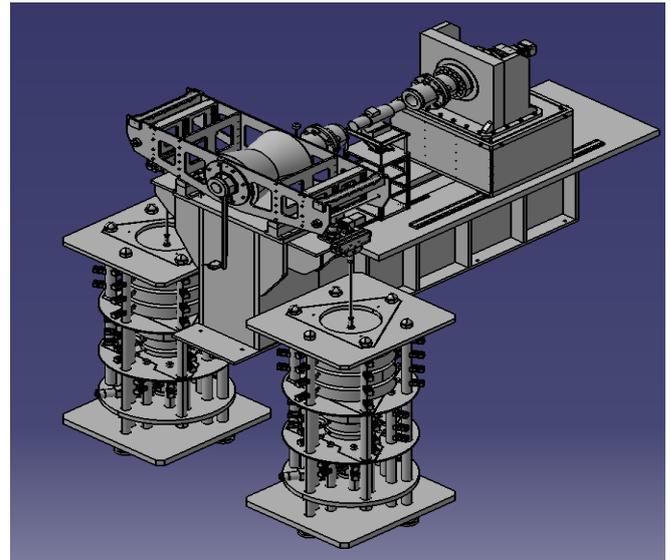


Fig. 1 A design of the 20 kN m deadweight torque standard machine in KRISS

We will use a new assembling technique for installation of the torque arm on the air-bearing as suggested by the manufacturer of the air-bearing shown in Fig. 2.

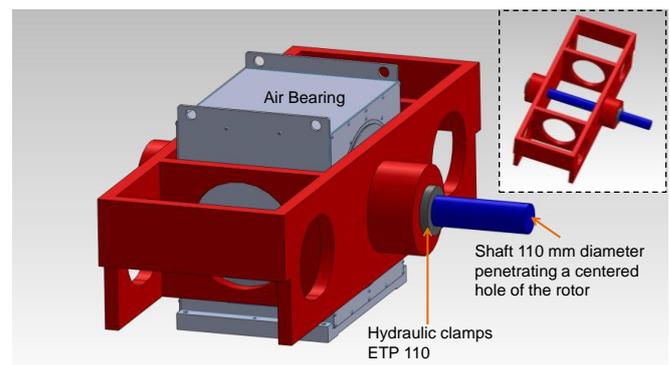


Fig. 2 New assembling technique for installation of the torque arm on the air-bearing provided by CEH. The inset clearly shows that the rotor of the air-bearing is not in the path of torque delivery.

Typically, double levers consisting of the torque arm are clamped to both sides of the rotor of the air-bearing through

bolts. In our case, a shaft with a diameter of 110 mm penetrating a 110 mm hole of the rotor is directly assembled with the torque arm using hydraulic clamps (or friction joints) such as ETPs. With this configuration, the rotor part of the air-bearing has nothing to do with the path of torque delivery so that the mechanical stress on the rotor can be minimized due to high torques.

The torque arm should be designed to have an enough structural stiffness to support 22 kN weights with minimized gross weight. The maximum deflection of the torque arm in a vertical direction should be less than 1 mm under 22 kN loads and its gross weight less than 700 kg. To increase a stiffness/weight ratio, two main plates comprising the torque arm have ribs of appropriate sizes and spacing. In addition, there are stiffeners that connect two plates transversely to increase structural stiffness of levers [1]. A finite element model will aid the design of the torque arm. The finite element model of a prototype design is shown in Fig. 2. The number of elements and their average size are 113,756 and 10 mm, respectively. The gross weight of the torque arm is estimated to be 678 kg.

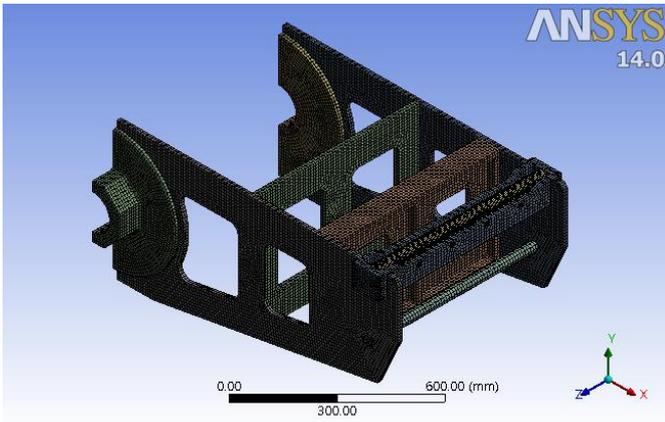


Fig. 3 A 3D finite element model of a prototype design of the torque arm.

At each end of the torque arm, a 70 μm -thick metal band is used for flexible connection between the torque arm and the weight stack. The metal band is clamped by wrapping itself along circumference of three cylindrical bars to minimize its wrinkles and frets, which are possibly generated when using bolts and a clamping plate. The length of the torque arm can be determined by measuring a distance L_0 between the centre of the air bearing and the centre of the round bar connecting two main plates. The effective torque arm length can be calculated by adding the radius of the connecting round bar and a half of the thickness of the metal band to L_0 . It should be noted that the deformation of the round bar in a longitudinal direction (X-direction in Fig. 3) is very important because it affects the effective torque arm length directly.

The finite element analysis shows that total deformation of the torque arm is smaller than 0.53 mm when a vertical load of 22 kN is applied to the metal band as depicted in Fig. 3. Most of deformation is in -Y-direction (gravity direction), so our requirement for the maximum vertical deflection of the torque arm (< 1 mm) is satisfied. However, more

important deformation is a change of the deflection of the connecting round bar in X-direction when a load is applied as mentioned previously.

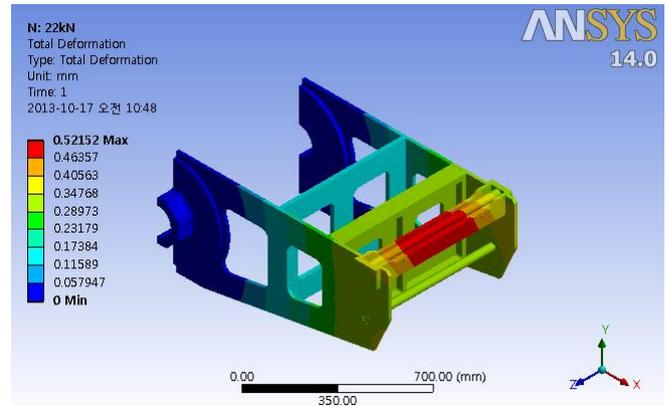


Fig. 4 One of the finite element analysis results: Total deformation of the torque arm when a 22 kN-load is applied.

The displacement of the centre of the round bar in X-direction was calculated as the load increases from 0 kN to 22 kN in steps of 2 kN in the finite element analysis. The result is shown in Fig. 4.

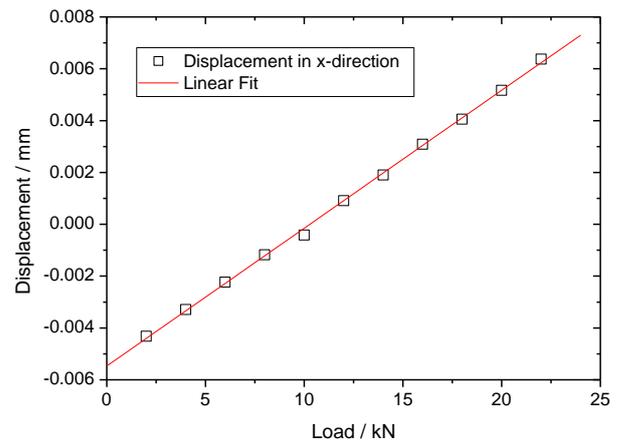


Fig. 5 A displacement of the centre of the connecting round bar against a load.

At zero load, the displacement was calculated to be about -5.5 μm . This initial deflection is due to the weight of the torque arm itself. We applied a gravity boundary condition (a body force) in our finite element analysis. Interestingly, the position of the centre of the connecting round bar moves in a positive x-direction (i.e. extending the effective length of the torque arm) as the load increases. The ratio of displacement to load is about 0.53 $\mu\text{m}/\text{kN}$. In normal case, the effective length of the torque arm gets shorter as the torque arm is deflected vertically downward. We need more investigation on how this simulation result could be obtained. One possible explanation is that the position of the assembly of three cylindrical bars holding the metal band is located between the centre of the air-bearing and the connecting round bar; the centre of the assembly of three

cylindrical bars is positioned at -0.5 mm in X-direction from the position of the centre of the connecting round bar. Thus, the load is not applied to the end of the torque arm. The extension of effective length could be attributed to this loading condition.

3. WEIGHTS AND COUNTER BEARING

Two same weight stacks of binary combination type connected to the right and left ends of the torque arm will be used to generate clockwise and anti-clockwise torques, respectively. A single weight stack comprising 11 weights (1 × 100 N, 2 × 200 N, 1 × 500 N, 1 × 1000 N, 2 × 2000 N, 4 × 4000 N) can generate deadweight forces from 100 N to 22,000 N in steps of 100 N. The weights are grouped into 3 according to their sizes in diameter. Each weight is supported by three adjustable stoppers fixed on a set of three cylindrical columns evenly spaced with 120° in plane. The stoppers can extend or retract in order to load the selected weight set. For each group of weights, a different set of columns is used to support weights more stably. So the total number of columns for stoppers is 9 (3 weight set × 3 columns). Fig. 6 shows a weight stack.

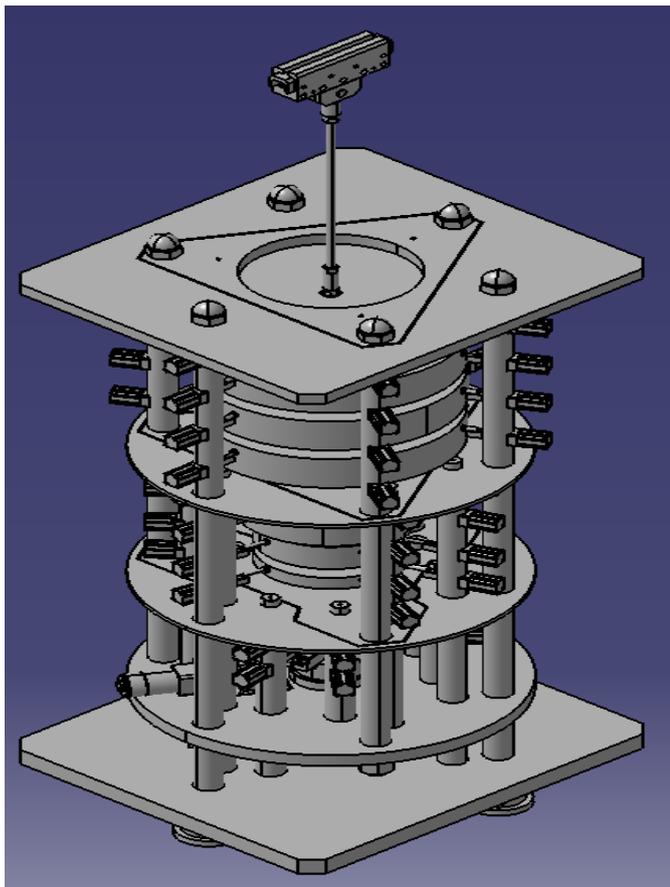


Fig. 6 A weight stack of a binary combination type

There is a lifting mechanism consisting of an electrical motor, other sets of columns and stoppers. For weight loading, the lifting mechanism moves up the all of columns so that the stoppers lift all of weights previously supported

by adjustable stoppers. Then, the adjustable stoppers retract only for the selected weights so that the selected weights are hung by the connecting rod. The unselected weights are supported again by the adjustable stoppers before they are loaded to the connecting rod. For each group of weights, a different set of columns is also used to lift weights more stably. So the total number of columns for the lift mechanism is also 9 (3 weight set × 3 columns).

The counter bearing consists of a servo-motor, a reduction gear and a stage with 5 degree of motion freedom for alignment of its axis to the air-bearing axis. A planetary gear assembly (reduction ratio of 220 or 302.5) with the maximum acceleration torque of 40 kN·m and 5 arcmin torsional backlash will be used. This high-torque reduction gear assembly enables a simpler counter-bearing design by substituting hydraulic components.

4. SUMMARY AND FUTURE WORK

The KRISS has launched a project developing 20 kN·m deadweight torque standard machine in response to industrial requests in 2013. It will be commissioned in 2016. The first design of the 20 kN·m KRISS torque machine is introduced and the finite element analysis was conducted for the torque arm. The analysis results show that the effective length of the torque arm gets longer as a higher load is applied to the torque arm. The amount of the extension is about 10 μm when a 22 kN weight is loaded. It is speculated that this is due to the position of the loading point. Further investigation will be conducted in order to validate the simulation results.

ACKNOWLEDGEMENTS

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5. REFERENCES

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