100Nm Negative Step Dynamic Torque Standard machine

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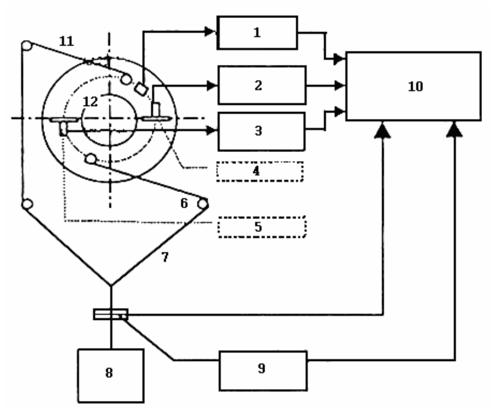
Abstract: The 100Nm negative step dynamic torque standard machine is used to calibrate the dynamic characteristics of torque transducer. Through measurement of negative step excitation time τ ,it can get the inherent frequency ω_n. The paper describes the working principle, key technology, test data and the uncertainty analysis of the machine. The specification of machine is as follows: measurement range 100Nm, $\tau \leqq 5$ms, uncertainty U=2.64%, k=2.

Keyword: dynamic torque, negative step, cylinder, τ , $\omega_{n.}$

1. Principle and Construction

1.1 Working Principle

The negative step excitation method is used to measure the dynamic characteristics of torque transducer and through the measurement of negative step excitation time τ to get the inherent frequency $\omega_{n.}$ ω_n is the main index of dynamic characteristics of torque transducer as shown in figure1.



1- amplifier of output signal of transducer
2- amplifier of charge
3- amplifier of charge
4- accelerator *1
5- accelerator *2
6- block
7- steel rope
8- weight
9- electromagnetic separator or cutter
10- acquisition and analysis device of dynamic signal
11- coupling
12- sensitive shaft

Fig1. step excitation method

To put a pure torque on the input end of torque transducer and the other end is fixed by a flange. When the steel rope is separated by electro-magnetic separator, the torque transducer is unloaded suddenly, the supported torque is zero ,and becomes a negative step torque. The signal of transducer enters into the acquisition device of dynamic signal , through data processing , the step torque drop step time τ is obtained and the ω_n value may be got by means of formula (1)

$$\tau = \frac{i}{\omega_n} tg^{-1}(-\sqrt{(1-\xi)/\xi}) \qquad (1)$$

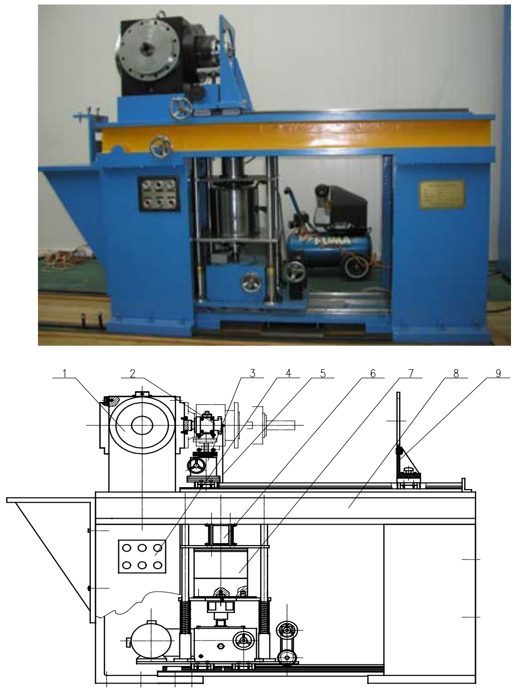
where :

τ -drop step time , s
ω_n-inherent frequency ,arc/s
ξ -damping coefficient(generally, 0.02- 0.03 is taken)

In order to verify the correctness of above mentioned data, it may be judged by the signal phase of accelerator and the frequency. After the output signal of two accelerators is sent to the signal acquisition device, the inherent frequency value may be determined according to the amplitude frequency characteristics, the phrase frequency characteristics and the phrase judge principle.

1.2 Construction

The 100Nm negative step dynamic torque standard machine consists of torque block, three-dimension working platform, electric controller, steel rope, cylinder, electro-magnet weight, base and torque wall etc. as shown in figure 2.



1- torque block
2- measured transducer
3- three-dimension working platform
4- electric controller
5- steel rope
6- cylinder
7- electro-magnet weight
8- base frame
9- torque wall

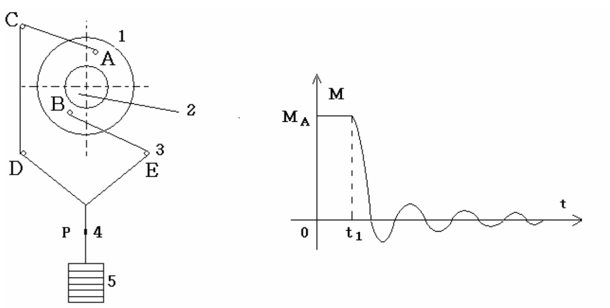
Fig2.100Nm negative step dynamic torque standard machine

One end of calibrated torque transducer is installed on the torque block and the other end is connected to the torque wall. The torque block is a big mass piece. The torque wall applies the negative step torque to the transducer, the step force is formed by the cylinder and the electro-magnet weight and is suspended on the pure torque wall to form a step torque. When the electro control PLC order is given, the electromagnet attracts the weight and the cylinder is charged with air to form a pulling force needed by 100Nm torque, and the 100Nm torque is supported by the transducer via the torque wall. When the electro-magnet is off, the reacting force of cylinder makes the steel nope weightless and go up quickly, the torque supported by the transducer disappears to zero and to form a negative step process. The negative step torque wave is acquired via the data acquisition device and the change time τ from 90% torque value to 10% torque value may be read, so the ω_n value may be obtained through data processing.

2. Key Technology

2.1 Production of Step Pure Torque

One end of measured transducer is fixed, on the other end a disk is put, the force F (weight) is applied on the A,B two points of disk, the distance from A,B points to the disk center, i.e the center of elastic shaft of transducer is L, the produced applied torque M=EL. To make the torsion bar of transducer carry only the pure torque and does not carry the bending moment (i.e the bending like cantilever beam produced by weight gravity)three support points C,D,E are added. The bending gravity is fully carried by C,E two points, and the A,B two ends can carry the symmetric pulling force and do not carry the gravity, as shown in fig 3



1- Coupling 2- sensitive shaft 3- block
4- steel rope 5- weight

Fig. 3 Principle of production of negative step signal

At the moment, the steel rope is cut off at P point quickly, the original torque value carried by torque transducer is $M=M_A$, during $t=t_1$, the torque value carried by torque transducer is $M=M_0$, the process of $M_A \rightarrow M_0$ forms a negative step torque and it is applied to the torque transducer.

2.2 Accelerated cut off Technology of Cylinder

When the electromagnetic separator is off ,the steel rope for transmission of torque loses its weight and goes up, the acceleration is only 1g,and it is difficult to produce τ =5ms negative step torque. Therefore, the accelerated cut off technology of cylinder is used. When the electro-magnetic separator is off, the cylinder activates, the weightless steel rope goes up rapidly, the acceleration arrives at 26g, the torque carried by transducer disappears and the gradient of drop step of negative step torque is increased greatly. The principle is as shown in figure 4.

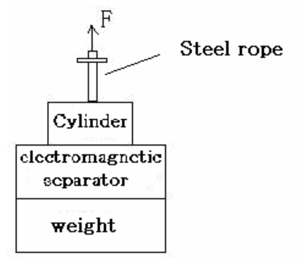


Fig.4a electromagnetic clutch module

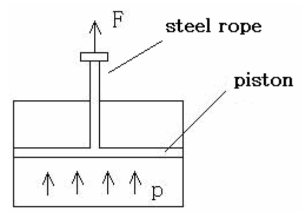


Fig. 4b principle of cylinder acceleration

After the weight is sucked up, the cylinder is charged with air to 8kg/cm^2. When the weight is separated from electromagnetic clutch, the pressure in cylinder pushes up the piston to make the piston go up quickly, the steel rope becomes flabby and the load of transducer vanishes into zero.

2.3 Stiffness and Inherent Frequency of Machine

The torque transducer is installed in a negative step standard machine to calibrate just like it is connected to a measurement chain and the quality and stiffness of machine will give an influence on ω_n value of transducer. For this reason, the calculation of stiffness and inherent frequency of base should be carried out correctly, so that the inherent frequency of negative step torque of standard machine is far away from the inherent frequency produced by the base and does not produce resonance or the influence is very small. According to the imitation of ADAMS software on the computer, about the quality of base, we suggest that the stiffness should be infinitely great, at least the inherent frequency should be more than 5 times of the inherent frequency of calibrated torque transducer.

3. Test Data

The data are calculated according to the time difference of 90%~100% torque value of drop step as shown in figure 5:

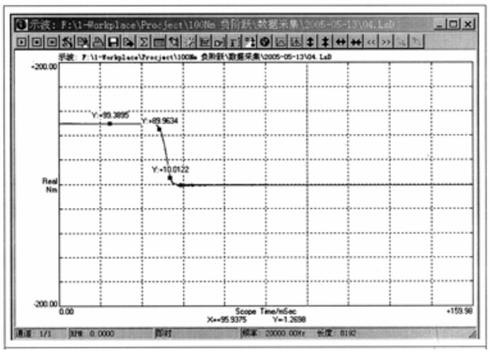


Fig.5 Wave of negative step torque

Measurement basis: The quartz crystal is taken as sensitive element in Kistler dynamic torque transducer. Its inherent response is very high and its inherent frequency is greatly higher than the inherent frequency of negative step 100Nm torque produced by standard machine, the time delay may be neglected and it is taken as standard to test the characteristics of standard machine.

Table.1 Test data

torque: 100Nm time : ms

No.	June,8,2005 afternoon		Time difference	error
	90Nm time	10Nm time		
1	39.0234	43.4766	4.4532	0.80%
2	39.0039	43.4766	4.4727	1.24%
3	39.0234	43.4375	4.4141	-0.09%
4	39.0234	43.4375	4.4141	-0.09%
5	39.0039	43.4766	4.4727	1.24%
6	39.0234	43.418	4.3946	-0.53%
7	39.0234	43.418	4.3946	-0.53%
8	39.0234	43.418	4.3946	-0.53%
9	39.0039	43.3789	4.375	-0.97%
10	39.0039	43.3984	4.3945	-0.53%

average of time differences: 4.42ms
repeatability: 2.21%
maximum difference: 1.24％

Calculation of data test standard difference:
4.4532 ms，4.4727 ms，4.4141 ms，4.4141 ms，4.4727 ms，4.3946 ms，4.3946 ms，4.3946 ms，4.3750 ms，4.3945 ms；

$$\bar{X}_2 = \frac{1}{10}\sum_{j=1}^{10} X_{2j} = 4.4180ms$$

$$s_2 = \sqrt{\frac{1}{10-1}\sum_{j-1}^{10}\left(x_{2j} - \bar{x}_2\right)^2} = 0.0354ms \qquad (2)$$

There is not any abnormal value (P=95% is taken) after distinguished by Grubbs rule.

4. Calculation of Uncertainty

4.1 The standard uncertainty component introduced by measurement repeatability u_{1rel}:

$$u_{1rel} = \frac{Sp}{\sqrt{3}\times\bar{x}} = 0.50\%$$

4.2 The standard uncertainty component introduced by the standard dynamic transducer u_{2re}:

The maximum allowable error of standard dynamic transducer: ±1.0% FS

Suppose it is distributed evenly:

$$u_{2rel} = \frac{1.0\%}{\sqrt{3}} = 0.58\%$$

4.3 The uncertainty component introduced by temperature u_{3rel}:

The temperature range of laboratory is: 20℃±5℃, the temperature coefficient of standard dynamic transducer is -0.02%/℃.

Suppose it is distributed evenly:

$$u_{3rel} = \frac{5\times 0.02\%}{\sqrt{3}} = 0.06\%$$

4.4 The standard uncertainty component introduced by the air pressure fluctuation of air compressor during testing time u4rel:

During the testing time the air pressure fluctuation is controlled within 0.2% and suppose it is distributed evenly

$$u_{4rel} = \frac{1\%}{\sqrt{3}} = 0.58\%$$

4.5 The standard uncertainty component introduced by the fluctuation of torque value during testing time u5rel:

The fluctuation of torque value is controlled within 0.2%, and suppose it is distributed evenly:

$$u_{5rel} = \frac{0.2\%}{\sqrt{3}} = 0.12\%$$

4.6 The standard uncertainty component introduced by reading the drop step time u6rel:

The minimum time interval of software for reading the drop step time is 02ms:

$$u_{6rel} = \frac{0.29\times 0.02\%}{\bar{x}} = 0.13\%$$

4.7 The composed standard uncertainty:

$$u_{crel} = \sqrt{u_{1rel}^2 + u_{2rel}^2 + u_{3rel}^2 + u_{4rel}^2 + u_{5rel}^2 + u_{6rel}^2} = 1.32\%$$

……………………………………… (3)

4.8 The expanded uncertainty:

k=2, $U = 2\times u_{crel} = 2.64\%$

5. Conclusion

As a result of four years' research of 100Nm negative step torque standard machine, the following goals have been realized: the frequency response is 1000Hz, the negative step signal is 100Nm, the drop step τ is 4.4ms (100±0.2Nm) and the uncertainty U=2.64%, k=2.

The loading way of machine has become an engineering, the PLC control is adopted, the loading is automatic, the produced signals are uniform, the repeatability is good and the components and parts of the machine will not be damaged in the whole process, and they can be used repeatedly.

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