The structure design of the calibration device for multi-component force and torque

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Abstract: This paper shows main characteristic of a multi-component calibration device as well as the working modes. The calibration device can generate continuous and combined load covering three forces of Fz, Fx, Fy and two moments of My, Mz, as well torque Mz. The emphasis is on mechanical design and simulation analysis of the device, which includes a main frame, a system generating reference load cells and piston-cylinder systems. The flexibility units have been specially designed to reduce the mutual influence between components generated. The performance verification results are given at the end of the article.

Key words: Multi-component, calibration device, structure design, simulation analysis, performance verification

1. Multi-component transducer

Each force vector in a certain 3-dimensional system of coordinate can be consider as a composition of 6 vectors, which are 3 forces (Fx, Fy, Fz) and 3 moments (Mx, My, Mz). The multi-component transducer is able to measure multiple component force and moment simultaneously.

Applying different types of sensitive material, there are two types of dynamometry, which are resistance stain type and piezoelectric crystal type. According to their structure, they can be divided into monolithic type and compound type (see fig1).

![fig1](image)

a) Piezoelectric crystal type  b) Resistance stain type  c) Compound type

Fig.1 Structure outline of multi component dynamometry transducer
2. Multi-component calibration device

In order to solve the comprehensive calibration problem of multi component transducer, a set of calibration device has been developed by CIMM. The device can be used to calibrate multi-component transducer either in a way of calibrating one vector independently, or in a way of calibrating 6 vector simultaneously. The technical parameter of the device is shown in table 1.

Table 1. Technical parameters of multi-component calibration device

| Component | Capacity | Relative expanded uncertainty \((k=2)\) |
|-----------|----------|---------------------------------|
| force     |          |                                 |
| Main (vertical) \(F_z\) | 250kN    | 0.03\%                          |
| Side \(F_x\), \(F_y\) | 100kN    | 0.05\%                          |
| moment    |          |                                 |
| \(M_x\), \(M_y\), \(M_z\) | 2000Nm   | 0.1\%                           |

3. Structure design of the device

By distributing multiple force sources in an appropriate way and loading by piston-cylinder system, all the load sources are able to function simultaneously and all 3 forces and 3 moments can be loaded synchronously and accurately.

3.1 Mechanical structure design of the main part

As it shown in fig2, the device is formed of a main frame, a load applied system and an piston-cylinder system. Loaders with suitable range are fixed in the coordinate system of force for space vector X, Y and Z respectively. Based on design requirement, each loader has one or more load force sources, whose outputs are linked to standard dynamometry. Different moments are provided by applying force away from center for a certain distance. By selecting and controlling the different force source harmoniously, at the operating platform the multi-component of force, moments or torque are loaded with force from different positions and directions, and thus all 6 components can be loaded individually or simultaneously.

![Fig2 Mechanical structure design of the main part](image-url)

The features of the main part of the device:

1) the 6 components are controlled with a good accuracy;
2) since the arms of force are fixed, it is convenient to measure and control;
3) sufficient test space, which can adjust altitude by moving the lifting mechanism;
3.2 Principle of load frame system

The 3D coordinate system of load is formed of piston-cylinder system on the load frame system. As it is shown in fig 3, loaders are designed at all coordinate axis (X, Y, Z), providing simultaneous multi-component load. Each piston-cylinder has its own dynamic system and a standard force transducer as reference, in order to measure and control the force accurately. They can be controlled in dependently or coordinately.

![Fig. 3 Structure of force load frame system](image)

![Fig. 4 Structure of primary component loader](image)

There are 5 loaders at vertical direction (Z), which are made in one loading system (see fig 4). With these loaders, main component Fz, moments Mx, My (both positive and negative) can be measured. When each loader of Z direction operates, the value of Fz, Mx, and My can be calculated as formula (1), formula (2) and formula (3).

\[
F_z = F_{z,o} + [F_{z,x}(+) + F_{z,x}(-)] + [F_{y,x}(+) + F_{y,x}(-)] + [F_{z,y}(+) + F_{z,y}(-)]
\]

\[
M_x = [F_{z,x}(+) + F_{z,x}(-)] - [F_{y,x}(+) + F_{y,x}(-)]
\]

\[
M_y = [F_{z,y}(+) + F_{z,y}(-)] - [F_{x,y}(+) + F_{x,y}(-)]
\]

Where \(F_{z,o}\) —— the force of the center loader in Z direction

\(F_{z,x}(+)\), \(F_{z,x}(-)\) —— the forces of two loaders in Z-X direction (Y is the same)

\(L_{z,x}(+)\), \(L_{z,x}(-)\) —— the arms of the two loaders in Z-X direction (Y is the same)

There are 8 loaders for horizontal plane (X-Y) of load frame system. The value of side force Fx, Fy and torque Mz (both positive and negative) can be acquired from these loaders. This design philosophy was similar to the force load in Z direction.

According to the design principle, the moment come from force, so moment produce force at the same time. According to the practical need, appropriate program need to be designed thoughtfully to compensate and accumulate the loading calculated.

3.3 Structure deformation regulation

The frame structure of the main part is the main body to take the load. Due to both the force, moment and torque are loaded multi-dimensional, when load position changes, the point of loaded force will swift, resulting in changes in load direction and arms of force. Thus, structure deformation need to be limited strictly, when the device is stressed, deformation in horizontal plane has evident effluence on stress position. The maximum deformation is less than 0.06mm. Deformation in vertical direction is caused by primary dimension force and it can be traced by exerting force with piston-cylinder system. The maximum deformation is less than 0.24mm. The details of deformation with maximum load are...
shown in fig 5.

![Deformation under maximum load of Fx, Fy, Fz](image)

Fig.5 Deformation under maximum load of Fx, Fy, Fz

3.4 Design of the flexibility mechanism

It is inevitable that each component generated by the device will be deformed when stressed being changed. Due to the deformation of transducers being calculated, the resulting in output axis of standard transducers and stress axis of the transducers being calculated will become unparallel. By attaching appropriate flexible components between loaders and standard transducers, the deformation can be traced in a limited displacement and parallelism of the axis of applying force and the axis of stress is assured. Meanwhile, interfere load is elevated to make sure force and torque outputted by the standard calibration device can be applied to instruments being calibrated.

4. Capability validation for multi-component device

In order to verify position relationship between each loader of the device, V-Star camera measure system is applied to measure distance and angle between each load axis. According to data analysis of the result, the maximum deviation of angle between measured value and criterion value among each load axis is 0.036° and the deviation of each effective arms of torque and moments is less than 0.1mm, which meets the design requirement.

High-accuracy standard force measuring instrument is applied to calibrate all 13 loaders. Each loader is calibrated by applying force load individually. The force accuracy of each loader is better than ±0.03%. Many multi-component transducers have been calibrated, the measurement results show that the device has good practicability and accuracy.

5. Conclusion

Many multi-component transducers have been calibrated, the measurement results show that the device has good practicability and accuracy. Experience will be required and more technical data will be collected, we will improve the capability of the device continuously.

6. References

[1] D. Girard, Development of multi-component force transducer standards by ONERA for French BNM. Proc. 11th IMEKO TC-3 Conf. 1986