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# Innovative Design of Long-range Linear Displacement Precision Measuring Mechanism for Airplane Trailing Cone Automatic Releasing System

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**Abstract**

As a kind of long-range winding system, positioning accuracy of airplane trailing cone automatic releasing system for airspeed calibration relies on linear displacement measurement accuracy of trailing cone automatic releasing process. Comparing several direct and indirect measuring methods, a dynamic long-range linear displacement precision measuring method for winding system based on magnetic rotary encoder is presented. Conceptual design of long-range linear displacement precision measuring mechanism according to proposed method is carried out. After error pre-analysis of several conceptual design schemes, a long-range linear displacement precision measuring mechanism based upon error avoidance theory is designed. The proposed measuring mechanism has been applied to conclude that its high accuracy, reliability and adaptability.



*Keywords: Trailing cone automatic releasing; Winding system; Long-range linear displacement; Magnetic Rotary Encoder; Errors avoidance; Precision measuring mechanism; Innovative design*

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## 1. Introduction

Airspeed calibration is an important item for airplane flight test, so that it is required to measure airplane static pressure at different flight altitude. International conventional airplane static pressure measurement method is that, trailing cone used for airplane static pressure measurement is put to proper position outside in flight process, and then air enters pressure sensor mounted within airplane through special pneumatic tubing cable. An airplane trailing cone automatic releasing system has been developed by authors for precision airplane static pressure measurement, which is a kind of winding system to transform rotational winding movement into linear movement. Its travel range may be from tens of meters to hundreds of meters. Position control accuracy affects the process quality of winding system heavily, which depends on displacement measurement accuracy in winding process. Linear displacement precision measurement in winding process is one of key technologies especially for long-range winding system.

The goal of this paper is to study a precision linear displacement measurement method with long-range oriented to airplane trailing cone automatic releasing system, and to develop a precision measuring mechanism based upon the proposed measurement method by utilizing error pre-analysis method and error avoidance theory.

## 2. Long-range linear displacement measurement method research

As mentioned before, the travel range of winding system usually is very large. In terms of measurement principle, both direct measurement and indirect measurement can be used to measure linear displacement of winding system. Direct measurement method is used to measure the linear displacement in winding process directly. There are many existing direct measurement technologies. For example, laser telemeter, laser interferometer, ultrasonic telemeter, radar-based sensor, stripe type long magnetic grating, inductosyn, grating transducer, capacitance measuring system, draw-wire displacement sensor, etc., are able to achieve precision measurement accuracy up to the mm, centi-mm, μm or even nm levels. However, the displacement measurement range with these technologies is considered too short to be accepted for linear displacement measurement of winding system. The measurement device based on these measurement methods is usually composed of detecting component and scale-plate. The scale-plate is mounted on the movement component, and the detecting component is mounted on the static component, usually on the slideway, which is required to have long travel range and enough straightness accuracy.

Transformation mechanism is required for indirect measurement of large-range linear displacement. For indirect measurement method of linear displacement in winding process, rotary encoder is often used to capture angular displacement at first, and then converted into linear displacement. Compared with direct measurement method, indirect measurement method covers a very large measurable range.

When selecting large-range linear displacement measurement method, both technical requirement and working condition of the measuring task are should be carefully considered. The measurement accuracy of ultrasonic telemeter can reach 0.5 mm, and is affected by working condition. Laser sensor and radar-based sensor have high accuracy, which is affected heavily by working condition. The measurement range of general noncontact measurement method is less than 20 m. Stripe type long-range sensor isn't suitable for large-range linear displacement measurement of airplane trailing cone automatic releasing system, because there is enough working space to install long-range slideway.

Optical encoder is a mature rotary encoder and angular sensor, and has a wide application. It can be used not only to measure angular displacement but also to measure linear displacement with the support of transfer mechanism. It is well known that a measurement system built with the technologies of optical encoder can achieve measurement accuracy up to the μm or even nm levels with relatively large measurement range. However, it is also noted that such technologies are suffering some weaknesses.

Optical encoder is affected by working condition, such as low temperature, vibration, wet atmosphere and pollution, and isn't applicable to airborne equipment.

Compared with other rotary encoders, magnetic inductive encoder is completely novel and has many advantages, such as simple structure, small size, high response speed and stability at high rotation speed, low cost and so on. It is usually applied to measure linear displacement of working stage of NC machine tool for position control. Being aimed at the specific measurement requirement and the working condition of airplane trailing cone automatic releasing system, indirect measurement method is adopted, and magnetic inductive encoder is finally employed as the precision measurement sensor of large-range linear displacement in winding process.

## 3. Innovative design of long-range linear displacement precision measuring mechanism

The existing methods to enhance the accuracy of precision equipment are usually complicated and of high cost. Error avoidance theory is a new concept appeared recently, which can be employed to minimize, eliminate and avoid the impacts of measurement error sources through effective technical approaches such as mechanism design. The ideal of error avoidance is that, some measurement error sources are under control and don't affect measurement accuracy at certain condition. As a complete new design concept, it emphasizes that, error should be designed, controlled and avoided actively. So innovative design of long-range linear displacement precision measuring mechanism will bases upon error avoidance theory [1].

### *3.1. Measuring mechanism conceptual design*

Primary problem of measuring mechanism design is how to install rotary encoder. As an indirect measurement sensor, magnetic inductive encoder is employed to measure angular displacement, which may be installed on the high speed axis, low speed axis of the machine or supplementary mechanism. Then there are three kinds of measuring mechanism design scheme respectively. The schematic diagrams of conceptual design of long-range linear displacement precision measuring mechanism are indicated in Fig. 1 to Fig. 3.

1) Design scheme I: High speed axis installation

As shown in Fig. 1, magnetic inductive encoder is installed on high speed axis, usually on the output axis of servo motor. This installation method has high resolution, and is suitable for high-accuracy unidirectional position control. Its shortage is that, the measurement accuracy is impacted by return journey gap error of reduction gears. It is required that the servo motor should be with slight vibration to prevent to damage the encoder.

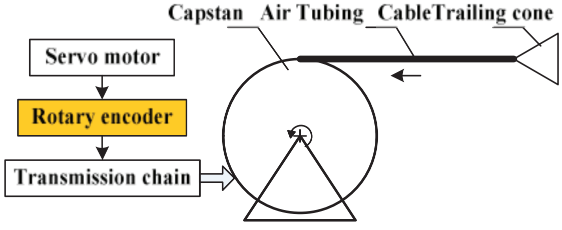



Fig. 1. Design scheme I: High speed axis installation

2) Design scheme II: Low speed axis installation

As shown in Fig. 2, magnetic inductive encoder is installed on low speed axis, usually on the output axis of the reduction box or reduction gear. Angular measurement accuracy of this installation method is unaffected by return journey gap error, which is suitable for large-distance positioning. As the winding diameter of the capstan changes gradually in winding process, it will make significant impact on linear displacement measurement.

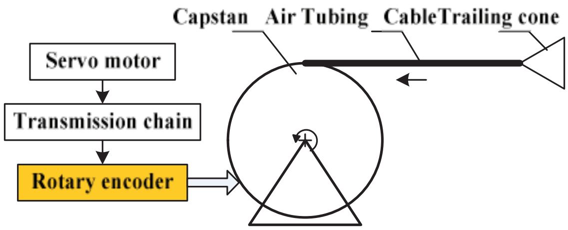
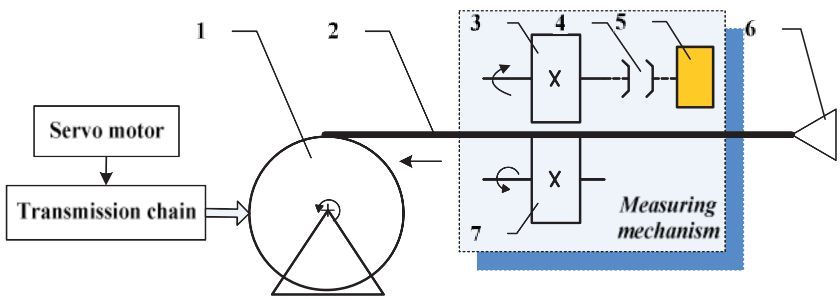



Fig. 2. Design scheme II: Low speed axis installation

3) Design scheme III: Supplementary measuring mechanism

As shown in Fig. 3, magnetic inductive encoder is not installed in the transmission chain of the mechanism of airplane trailing cone automatic releasing system, but rather on independent supplementary mechanism, which is called measuring mechanism or meter counter mechanism. Gear, gear rack, belt, chain, friction roll wheel, etc. can be employed for such supplementary mechanism.




1-Capstan, 2-Pneumatic tubing cable, 3-Measuring roll wheel, 4-Flexible coupling, 5-Rotary encoder, 6-Trailing cone, 7-Guidance wheel

Fig. 3. Design scheme III: Supplementary measuring mechanism

### *3.2. Measurement error pre-analysis and evaluation of measuring mechanism design scheme*

To ensure high design accuracy, pre-analysis and evaluation of measurement error is necessary during measuring mechanism design. Main error resources corresponding to three kinds of measuring mechanism design scheme are shown in table 1.

Table 1 Main error resources of three kinds of measuring mechanism design scheme

| *Error Resource* | *Scheme I* | *Scheme II* | *Scheme III* |
|---|---|---|---|
| Manufacturing error of encoder | √ | √ | √ |
| Installation error of encoder | √ | √ | √ |
| Transmission chain error | All | Part | - |
| Return journey gap error of gear transmission | √ | - | - |
| Conversion error by winding diameter change | √ | √ | - |

Main error resources of measuring mechanism include manufacturing error of rotary encoder, installation error of rotary encoder, motion error of mechanic transmission chain of airplane trailing cone automatic releasing system, measuring mechanism error and so on. The motion error of mechanic transmission chain includes motion error of every transmission gearing, the return journey gap error of gear transmission, forward and reversal error corresponding to drawing back and putting out action and so on. Both for design scheme I and II, there is also conversion error from angular displacement to linear displacement caused by winding diameter change of the capstan. It is obvious that, more winding diameter change, more conversion error.

Shortest Transmission chain principle ought to be obeyed in precision automatic measuring instrument design to assure measurement accuracy [1]. As for design scheme III, the number of error resources is reduced to minimum, many measurement error resources are avoided and deleted entirely, and measuring accuracy is the highest, which is only impacted by manufacturing error and installation error of rotary encoder itself. Therefore design scheme III is finally adopted.

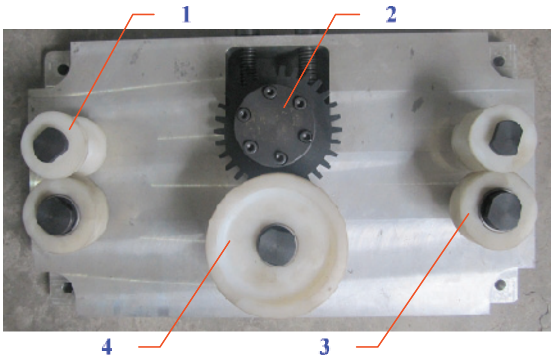
### *3.3. Mechanical structure design of measuring mechanism*

The configuration of measuring mechanism based on design scheme III is illustrated in Fig. 3.

The measuring mechanism is based on rolling friction drive. The magnetic inductive encoder and the measuring roll wheel are jointed together co-axially by a precision flexible coupling. When the pneumatic tubing cable is put out or drawn back automatically at a certain speed, the measuring roll wheel is pulled to rotate because of inverse rolling friction. Angular displacement and the direction of the measuring roll wheel can be detected by the magnetic inductive encoder and transformed into electronic pulsing signal, and then the linear displacement of the pneumatic tubing cable is calculated automatically by conversion software.

The proposed measuring mechanism has many advantages. It’s not necessary to install measurement component on movement components and static components separately or to lay special guide way. Its measurable range is infinitely great theoretically. The transmission mechanism error doesn’t affect measurement result, because magnetic rotary encoder is installed on measuring mechanism which is independent to transmission mechanism.

The long-range linear displacement precision mechanism has been developed and applied for airplane trailing cone automatic releasing system, and a photograph of it is shown in Fig. 4.




1, 3-Tension Wheel, 2-Measuring roll wheel + Encoder, 4-Guidance wheel

Fig. 4. Photograph of the proposed precision measuring mechanism

The proposed measuring mechanism has been tested to conclude that, its measurable range is 100 m, and that the linear displacement measurement error is less than 25 mm with a total travel of 100 m.

## 4. Conclusion

(1) An innovative design method for precision mechanism and instrument is provided, which is based on error pre-analysis and error avoidance, and is the advancement of design method in metrology in general.

(2) A long-range linear displacement precision measuring mechanism based upon magnetic rotary encoder has been designed and developed, which can realize long-range linear displacement precision measurement, and has been applied in airplane trailing cone automatic releasing system successfully. Its measurement accuracy is 25mm/100m. It has high reliability and works well in abominable environment.

(3) The proposed measuring mechanism is better in simplicity and universality, and can be also easily applied to other similar winding systems for precision measurement of long-range linear displacement.

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