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# Development of Device for Optical Measurement of Spin Rate of Wind Tunnel Models

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**In wind tunnel tests of free-spinning missile models it is of interest to measure the rotation rate of the models. As it is essential to provide free rotation of such models with minimum friction in the bearings, the instrumentation for measuring the rotation rate must not introduce any additional braking torque so that contactless measurement is preferred. Also, instrumentation must fit in the constrained space in the model, most of which is usually occupied by a wind tunnel balance. A simple device for optical measurement of the rolling rate of the models for the T-35 wind tunnel was developed in the Military Technical Institute in Belgrade. The device comprises two infra-red optical proximity switches and a black/white striped mask mounted on a convenient coaxial cylindrical surface inside the model. The outputs from the optical switches are fed through a conditioner into the wind tunnel data acquisition system. Rotation rate is determined from the measurement of the frequency of pulses generated by the switches when the striped mask is rotating in their field of view. Furthermore, as the optical mask is produced with two ribbons of stripes phase-shifted by 1/4 of the period, so that the outputs of the optical switches are in quadrature, the direction of rotation can be detected**

*Key words*: **wind tunnel testing, wind tunnel model, rotation, free rotation, rotation rate, speed measurement, optical device.**

## Introduction

IN wind tunnel tests of missile models with canted fins [1]-[3] it is usual to provide free rotation of the model along its longitudinal axis. This is achieved by mounting the model on a pair of low-friction roller bearings attached to the metric part of an internal wind tunnel balance in the model. Minimization of the friction is so imporant that sometimes air bearings are used instead of roller bearings [4]. Furthermore, it is of interest to measure the spinning rate of such models. As it is essential that the free rotation is achieved with minimum friction, the instrumentation for measuring the rotation rate must not introduce any additional braking torques. Therefore, contactless measurement is preferred. Also, the device used to measure the rotation rate must fit into the constrained space in the model, most of which is usually occupied by a wind tunnel balance.

Manufacturers of position transducers produce rotary angle encoders without integral bearings, in which there is no physical contact between the rotor and stator parts, such as the ECA, ERP, ERA and other series of encoders by Heidenhain [5] and other manufacturers. Of those, the Heidenhain ERA series is of a particular interest because it features a static scanning head and a “scale tape” [5] (a grated magnetic or optical mask) which is cut to a desired length and glued to the rotating member that is monitored. During the rotation, electric pulses are produced by the scanning head as the scale tape passes in its field of view, and the pulses are thereafter converted into velocity and/or position data.

However, the stators (scanning heads) of commercially available position encoders of this type are usually relatively large and not suitable for installation in the restricted space available in a typical wind tunnel model sized for testing in the wind tunnels of the Military Technical Institute (Vojnotehnički institut – VTI, Belgrade). Also, as each wind tunnel model is practically unique in design, new tape segments, cut to lengths suiting particular model geometries would have to be used in each model, increasing its price. Besides, commercially available encoders are said to be “over-engineered” for the purpose because they usually have mask periods of about 20-80 μm [5]. In a typical model, this would correspond to the angular resolution of the sensor smaller than 0.05° which, in most cases, is not really necessary for determining the rate of spin.

A simple low-cost solution for measuring the rotation rate of freely spinning models in the T-35 and T-38 wind tunnels of VTI was developed as an alternative to the expensive and too-large commercial transducers. The solution deploys a concept somewhat similar to the one used in the CNA-series encoders, and comprises two miniature infra-red optical proximity switches mounted on the non-rotating inner part of the model (i.e. on the balance-model interface adapter on the metric side of the internal balance), The switches detect the movement of a black-and-white grated optical mask installed on the rotating outer shell of the model, each producing a pulse whenever a stripe on the mask passes in the field of view of the sensor. The optical mask (Figures 1 and 2) consists of two grated ribbons, each with black stripes on a white background. The stripes on two ribbons are shifted from each other by 1/4 of the stripe period, so that the pulses produced by the optical sensors detecting the movement of the

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mask are in quadrature, and the direction of the movement can be detected, as the pulses from the two sensors are phase-shifted by 90º.


**Figure 1.** The optical mask with two ribbons of stripes

The striped mask is produced by printing, in a laser printer, on a self-adhesive paper or foil. After printing, the mask on the self-adhesive paper is cut to appropriate dimensions and attached to a suitable cylindrical inner surface on the rotating part of the model, so that it forms a continuous loop (Fig.2).

**Figure 2.** Striped mask attached to a rotating ring used for transducer tests

The length of the mask and the stripe interval depend on the circumference of the cylindrical surface on a particular wind tunnel model (inner diameters of the models are most often between 50 and 150 mm). A convenient number of stripes on each ribbon is 60, because, in such case, the frequency of the pulses detected by the scanning head is numerically identical to the number of revolutions per minute, but other stripe counts are sometimes used, depending on the expected rotation rate of the model and the sampling rate of the wind tunnel data acquisition system used to record and process the pulses. With 60 stripes per ribbon, the angular resolution of the device is 6º, which is usually sufficient.

## Description of the transducer and the signal conditioner

The scanning head of the transducer consists of two CNY70 optical reflective sensors, Fig.3 [6]. Each CNY70 comprises an infrared LED (light-emitting diode) and a phototransistor (Fig.4). In the presence of a reflective surface at an appropriate distance from the sensor, light emitted by the LED is reflected to the phototransistor which is made conductive. Dimensions of the sensor are just 7×7×6 mm so that several sensors can usually be installed side by side in a wind tunnel model, sometimes directly in a suitable slot in the model body, and sometimes on a small base board (Fig.6).

Two CNY70 sensors are installed in a model so that they are oriented towards the rotating cylindrical surface onto which the optical mask is glued, taking care that one sensor illuminates one of the ribbons on the mask and another sensor illuminates another ribbon. The capture distance of the CNY70 sensor is 0-5 mm so that the positioning tolerances are not strict. If the (infrared) light emitted by the LED drops on a black stripe on the ribbon it is mostly absorbed and does not reflect to the base of phototransistor so the phototransistor is not conducting. If the light drops on a white stripe on the ribbon it is mostly reflected and reaches the base of phototransistor so the phototransistor is conducting. Changes in the current through the transistor are converted to TTL voltage levels using a simple signal conditioner installed elsewhere in the model or in the model support. Although the sensor operates at infrared wavelengths, it has been found that it works satisfactorily with a printed mask which is black and white in visible light, and the spatial resolution of the stripes is about 2 mm

**Figure 3.** CNY70 optical proximity switches

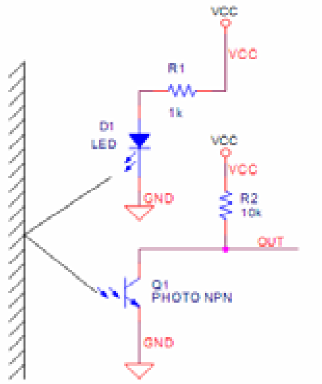


**Figure 4.** Principle of work of the CNY70 optical reflective sensor

Fig.5 shows the schematics of the scanning head of the transducer with two CNY70 sensors light-emitting diodes are in serial connection so that a single supply line is used, and the connection to the signal conditioner is a four-wire one. Current through the light-emitting diodes is controlled by a resistor in the signal conditioner.

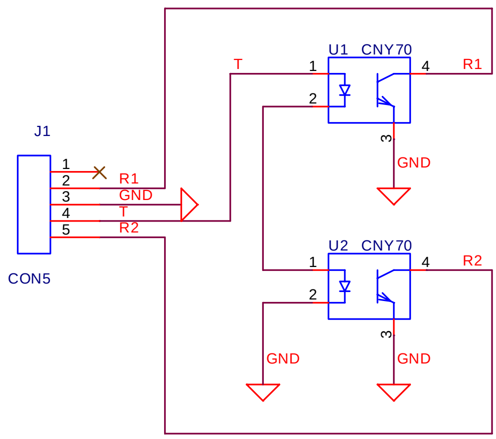


**Figure 5.** Schematics of the transducer with connector

Fig.6 shows the scanning head with two CNY70 sensors and a miniature connector. The form factor of the implementation of the head shown in the figure (the sensors and the connectors mounted on a 7 mm wide and 70 mm long PCB strip) was dictated by the available space in the body of a particular wind tunnel model.

**Figure 6.** Two CNY70 sensors on a 7 mm wide base board prepared for mounting in a wind tunnel model. The connector is on the left.

Fig.7 shows the schematics of the simple signal conditioner used with the scanninng head.

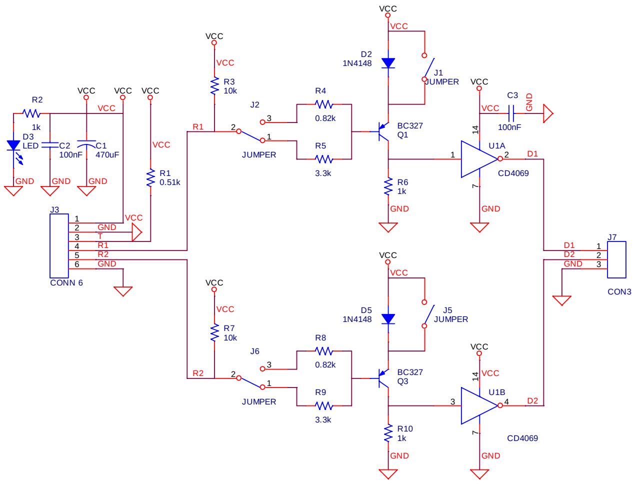


**Figure 7.** Schematics of the signal conditioner

For each of the two sensors, the conditioner comprises a single-stage amplifier implemented by a BC327 transistor (Q1, Q2) and a signal-shaper implemented by an inverter gate in a CD4069 chip. Possible model-to-model variations in the signal outputs from the CNY70 sensors, which may be a consequence of distances of the optical mask from the sensors, are compensated by the deployment of the jumpers J1, J2, J5, J6 in the conditioners by which the sensitivity of the preamplifier stage can be adjusted.

The outputs of the signal-conditioner are trains of TTL-level pulses which are in phase with the passage of the optical masks in the fields of view of the CNY70 sensors. When a white stripe on the optical mask is detected by the sensor, the phototransistor in the sensor conducts and causes the preamplifier transistor in the conditioner to conduct, which results in the logical zero on the output of the conditioner. The opposite is valid when a black stripe on the optical mask is detected.

Fig.8 and Table 1 show the four signal patterns which can be detected by the sensor. As the two trains of pulses are phase-shifted by ¼ of the period, the direction of the rotation can be ascertained, depending on whether the zero-to-one transition on the first sensor occurs when the signal from the second sensor is at logical zero or at logical one.

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |

**Figure 8.** Signal patterns detected by the scanning head

**Table 1.** Four possible signal patterns detected by the scanning head

| Optical sensor 1 | Optical sensor 2 | Digital signal |
|---|---|---|
| white | white | 00 |
| white | black | 01 |
| black | white | 10 |
| black | black | 11 |

The described sensor setup can be easily expanded by the addition of the third optical sensor and the third stripe on the optical mask, with just one mark. The pulse generated by the added sensor can be used for indexing, determining the rotation angle of the model at the moment of occurrence of the pulse. The actual roll angle of the rotating model during the measurement can then be detected by counting the pulses from the optical sensors, taking into account the number of stripes on the optical mask. The resolution of the angle measurement is equal to the angular distance between the two adjacent stripes on the mask, i.e. 6º if each ribbon on the mask has 60 black-and-white stripes.

## Data acquisition

In the current version of the test setup, the outputs from the signal conditioners are routed to two bits of the input to a parallel-digital-input card on the wind tunnel data-acquisition system. The frequency of pulses and the direction of rotation are determined during the data processing. However, other data-acquisition setups are possible. For example, the signals can be routed to the inputs of a counter/frequency-meter card if such is available, on the system, or they can be routed to the inputs of a quadrature-detector card if such is available.

If the frequency of the pulses is determined during the data processing (which is currently the case during the wind-tunnel data processing in VTI), any of several available methods (e.g. FFT) for determining the frequency spectrum of a signal can be used. As the signal is a composition of two trains of "square" pulses, comprising a number of higher harmonics, only the frequency of the lowest harmonic should be evaluated.

If the signal from the transducer is accepted by a counter/frequency input of the data acquisition system, the output from the system, the frequency of the signal from the transducer will generally be determined by counting the pulses against a fixed reference clock signal. The output format of the computed frequency will depend on the data acquisition system.

## Conclusion

The presented design is a simple, low-cost solution for the measurement of the rotation rate of freely spinning wind tunnel models of missiles. Furthermore, the direction of rotation (which sometimes changes with the angle of attack of the model, depending on the positions and deflections of the control surfaces) can be detected. With a minimal increase of complexity, the angular position of the model in roll can be deduced as well. The device is connected either to a parallel-digital-input channel of a wind tunnel data acquisition system or to frequency counter inputs, or to quadrature-decoder inputs, if any of them is available. As the cost of the required components is trivial, the device can be permanently installed during the production of the model and need not be retrieved after the wind tunnel test. The concept therefore provides more freedom for the model designer than if a commercial angular-position encoder was used.

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# Razvoj uređaja za optičko merenje brzine obrtanja aerotunelskih modela

**U aerotunelskim ispitivanjima slobodno rotirajućih modela projektila od interesa je da se odredi brzina obrtanja modela. Kako je vrlo važno da se obezbedi slobodna rotacija modela sa minimalnim trenjem u ležajevima, instrumentacija za merenje brzine obrtanja ne sme izazvati nikave dodatne kočione momente pa se preferira beskontaktno merenje. Pored toga instrumentacija se mora smestiti u ograničeni prostor u unutrašnjosti modela, čiji najveći deo je popunjen aerovagom. Razvijen je jednostavan uređaj za optičko merenje brzine rotacije modela za aerotunel T-35 u Vojnotehičkom institutu. Uređaj sadrži dva infracrvena optička blizinska prekidača i crno-belu prugastu masku postavljenu na pogodnu cilindričnu unutrašnju površinu u modelu. Izlazni signali sa optičkih prekidača se dovode na kondicioner, a zatim uvode u aerotunelski sistem za prikupljanje podataka. Brzina rotacije se određuje iz merenja frekvencije impulsa koje proizvode prekidači kada se prugasta maska obrće u njihovom vidnom polju. Pored toga, kako se optička maska pravi sa dva reda pruga smaknutih za 1/4 perioda tako da su izlazni signali optičkih prekidača u kvadraturi, može se odrediti smer rotacije.**

*Ključne reči:* **aerodinamičko ispitivanje, aerodinamički model, rotacija, slobodno kretanje, brzina obrtanja, merenje brzine, optički uređaj.**

# Développement des instruments pour le mesurage optique de la vitesse de rotation des modèles de soufflerie

**Dans les essais effectués dans le tunnel aérodynamique des modèles librement rotatifs des projectiles il est d'intérêt de déterminer la vitesse de rotation du modèle. Comme il est très important d'assurer la rotation libre du modèle avec la friction minimale des logements l'instrumentation pour le mesurage de la vitesse de rotation ne doit pas provoquer les moments additionnels de freinage de sorte qu'on préfère un mesurage sans contact. A part cela l'instrumentation doit être placée dans l'espace limitée à l'intérieur du modèle dont la plupart est remplie par la balance de soufflerie. Un instrument simple a été développé pour le mesurage optique de vitesse de rotation pour le modèle de soufflerie T-35 à l'Institut militaire. Cet instrument comprend deux interrupteurs optiques infrarouges et un masque noir et blanc rayé posé sur la surface cylindrique intérieure dans le modèle. Les signaux de sortie des interrupteurs optiques sont conduits sur le conditionneur et ensuite on les introduit dans le système du tunnel aérodynamique pour ramasser les données. La vitesse de rotation se détermine par le mesurage de la fréquence des impulsions produites par les interrupteurs lorsque le masque rayé tourne dans leur champ de vision. En outre comme le masque optique est produit à deux rangs de raies éloignés de ¼ de période de sorte que les signaux optiques des interrupteurs se trouvent en quadrature on peut déterminer le sens de la rotation.**

*Mots clés:* **essai aérodynamique, modèle aérodynamique, rotation, mouvement libre, vitesse de rotation, mesurage de vitesse,instrument optique.**

# Разработка устройства для оптического измерения скорости вращения аэротоннельных моделей

**В испытаниях аэротоннельных свободно вращающихся моделей снарядов очень важно и необходимо определить скорость вращения модели. Поскольку очень важно обеспечить свободное вращение моделей с минимальным трением в подшипниках, прибор для измерения скорости вращения не должен вызывать никаких дополнительных тормозных моментов, поэтому предпочтительным является бесконтактное измерение. Кроме того, прибор должен располагаться в ограниченном пространстве внутри модели, большая часть которого заполнена аэровесами. В Военно-техническом институте было разработано простое устройство для оптического измерения скорости вращения модели для аэротоннели Т-35. Устройство содержит два инфракрасных оптических бесконтактных**

**переключателя и чёрно-белую полосатую маску, размещённую на подходящей цилиндрической внутренней поверхности в модели. Выходные сигналы от оптических переключателей подаются в кондиционер, а затем вводятся в систему сбора данных аэротоннели. Скорость вращения получается из измерения частоты импульсов, создаваемых переключателями, когда полосатая маска поворачивается в своём поле зрения. Кроме того, поскольку оптическая маска выполнена с двумя рядами полос, отснятыми за 1/4 периода, так что выходные сигналы оптических переключателей находятся в квадратуре, можно определить направление вращения.**

*Ключевые слова:* **аэродинамические испытания, аэродинамическая модель, вращение, свободное перемещение, скорость вращения, измерение скорости, оптическое устройство.**