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One Component Transducer for Measuring the Rolling Moment on the Missile Model

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Description of a specially constructed one component transducer for measuring the rolling moment on the missile model is given in this paper. The range of measurement of this transducer is 1 Nm and the accuracy is 0.02 %. This accuracy is ten times bigger than the accuracy of the strain gauge balances which is in use. During this experiment, this one component transducer has shown as very reliable measurement element, which will be in use in laboratories of experimental aerodynamics.

Key words: **wind tunnel, one component transducer, missile model, rolling moment, experimental aerodynamics.**

Nomenclature

C_{l0}	– coefficient of the rolling moment for angle attack $\alpha = 0^\circ$
d	– model diameter [m]
e	signal from measurement bridge [V]
E	modulus of elasticity [N/ m^2]
$F_{A,B}$	force [N]
$K(1)$	balance calibration coefficient [Nm/V/V]
l_m	model length [m]
L	rolling moment [Nm]
$M_{x,A,B}$	bending moment [Nm]
M	Mach number
U	measurement bridge supply voltage [V]
ν_D	factor of safety
FS	full scale (nominal) load range of the transducer
ε_{ef}	effective elongation
w	section modulus [m^3]

Introduction

MAXIMUM expected value of the rolling moment on the missile model with wrap around wings or rectangular wings, for all the predicted Mach numbers, angles of attack and model configurations in these tests was 0.6 Nm [1]. The expected value of the rolling moment is very small and therefore it was necessary to design and manufacture one component transducer for measuring the rolling moment with greater precision. This transducer had to be able to withstand large transitional loads generated on the model when starting and stopping the wind tunnel. Having been manufactured, the transducer was calibrated. Most tests were done for the angle of attack $\alpha = 0^\circ$, for different Mach number and different wing built-in angle. The test of repeatability for ten runs with the same parameters in the test section of the wind tunnel was also done. The purpose of these ten runs was to confirm transducer's reliability and accuracy by value of standard deviation.

Model description

The model wing section consists of four wings. There are two model configurations: with wrap around wings or with rectangular wings, Figures 1 and 2. Ratio of the model length and model diameter is $l_m / d = 16.5$. There are two complete sets of wrap around wings: with bend in watch hand direction and in the opposite direction. Built-in angles of wrap around wings and rectangular wings with regards to the model across axis can be: 0°, 0.2°, 0.8°.

Figure 1. Wrap around wings of model MODEL01

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Figure 2. Rectangular wings of model MODEL01

Test facility –wind tunnel T-38

The wind tunnel T-38 test facility at the Military Technical Institute in Belgrade is blowdone-type pressurized wind tunnel with a 1.5m x 1.5m square test section. For subsonic and supersonic tests, the test section has solid walls, while for transonic tests, a section with porous walls is inserted into the tunnel configuration. The porosity of the walls can be varied between 1.5% and 8% depending on the Mach number, so as to achieve the best flow quality. Mach numbers in the range of 0.2 to 4.0 can be achieved in the test section, with Reynolds number up to 110 million per meter. In the subsonic configuration, Mach number is set by the flexible nozzle contour, while in the transonic configuration, Mach number is both set by sidewall flaps and the flexible nozzle, and actively regulated by the blow-off system. Mach number can be set and regulated to within 0.3% of the nominal value.

Instrumentation, data recording and reduction

The data acquisition system consisted of a Teledyne 64 channel "front end" controlled by a PC Compaq computer. For one component transducer, a filter of 30Hz and channel gain of 1024 were set. Supply voltage applied to the measuring bridge was 6V. Date sampling rate was 200data/s.

Data reduction was performed after each run, using the standard T38-APS software package in use with the wind tunnel facility. It was done in several stages, i.e.:

- data acquisition system interfacing and signals normalizing
- determination of flow parameters
- determination of the model attitude
- determination of the aerodynamic coefficient.

Each stage was performed by a different module.

One component transducer for measuring the rolling moment

One component transducer for measuring the rolling moment on the model MODEL01 is shown in Fig.3. It was manufactured in the form of a ring with four measuring beams [2].

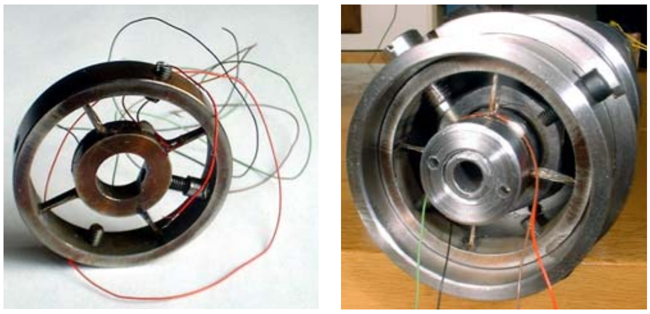

Figure 3. One component transducer for measuring the rolling moment

Transducer is connected to the ring with four screws. The ring is linked to the model body, where the rolling moment is generated. The structure of one component transducer, ring, adapter and six-component mono-block internal balance for measuring others aerodynamics loads are shown in Fig.4.

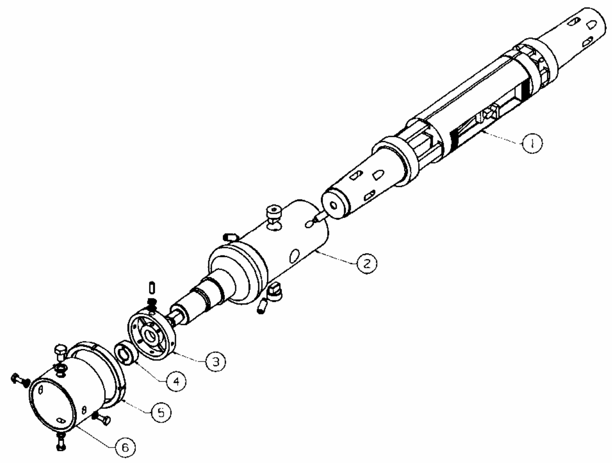

Figure 4. Structure of one component transducer and six-component balance

Internal six-component balance VTI38A is marked with number 1, one component transducer is marked with number 3. Numbers 2 and 6 mark the adapter and ring for transducer connection with the model body, and numbers 4 and 5 mark the safety nuts.

Deformation of the measuring beam by action of the rolling moment L is shown in Fig.5. The scheme of measuring beam load and beams cross-section are shown in Fig.5, too.

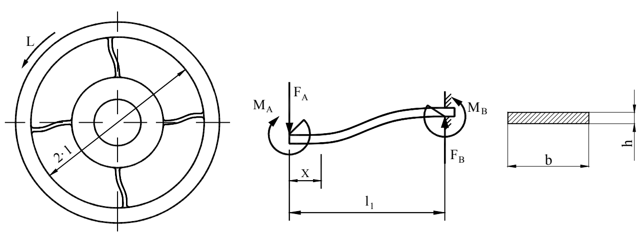

Figure 5. Deformation of the measuring beam

One component transducer is designed in such a way that for the rolling moment of $L = 0.6\,\text{Nm}$ the value of the measuring bridge output signal satisfies all requirements, but at the same time this transducer has to be able to withstand large transitional loads that are generated on the model at starting and stopping of the wind tunnel $\left(L_p = 2\,\text{Nm}\right)$. Transducer is manufactured from ARMCO

PH13-8 steel.

The force on a measuring beam is obtaining by the following formula:

$$F_A = \frac{L}{4 \cdot l}$$

where:

- $L = 0.6\text{Nm}$
- $l = 1.7\text{cm}$ (distance from the measuring beam front edge to the rolling axis).

Measuring beam cross-section section modulus is:

$$w = \frac{b \cdot h^2}{6}, \ (b = 0.2\text{cm} \quad h = 0.075\text{cm}).$$

Strain gauges position and measuring bridge scheme are shown in Fig.6.

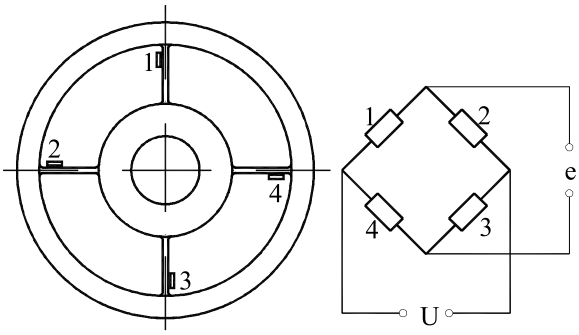

Figure 6. Measuring bridge scheme

Bending moment, normal stress and elongation at the areas where the strain gauges are cemented [3, 4] are:

$$M_A = \frac{F_A \cdot l_1}{2} - F_A \cdot x$$

$$\sigma = \frac{M_A}{w} = 941.176 \frac{\text{daN}}{\text{cm}^2}.$$

$$\varepsilon = \frac{\sigma}{E}, \quad (\varepsilon_{ef} = 4 \cdot \varepsilon)$$

where:

- $x = 0.2\text{cm}$ (distance from the strain gauge center to the measuring beam front edge)
- $l_1 = 0.8\text{cm}$ (measuring beam length).

Nominal values of the output signal for the rolling moment $L = 0.6\text{Nm}$ and measuring bridge supply voltage of 6V is:

$$e = \frac{\varepsilon_{ef}}{4} \cdot U \cdot k = 5.647 \cdot 10^{-3} V$$

where:

- $k = 2$ (strain gauge sensitivity factor).

Factor of safety at the critical cross section (root of the measuring beam) is calculated according to the rolling moments that are generated on the model at starting and stopping of the wind tunnel. According to this value of the rolling moment, L_p=2Nm, the force on a measuring beam will be:

$$F_p = \frac{L_p}{4 \cdot l}.$$

Bending moment at the root of the measuring beam is:

$$Mp = \frac{F_p \cdot l_1}{2}.$$

Normal stress and factor of safety at the root of the measuring beam are:

$$\sigma_u = \frac{M_p}{w} = 6.275 \cdot 10^3 \frac{\text{daN}}{\text{cm}^2}, \ \nu = \frac{\sigma_D}{\sigma_u} = 1.12$$

$$\sigma_D = 7000 \frac{\text{daN}}{\text{cm}^2}.$$

Calibration of one component transducer

One component transducer was calibrated as part of the model in the wind tunnel test section [5]. Application of loads is shown in Fig.7. Six weights, each of 0.5kg mass were used for calibration. Calibration diagram, calculated calibration coefficient and error diagram are shown in Figures 8 and 9.

Comparison of theoretical values of the output signal and measured output signals is given in Table 1.

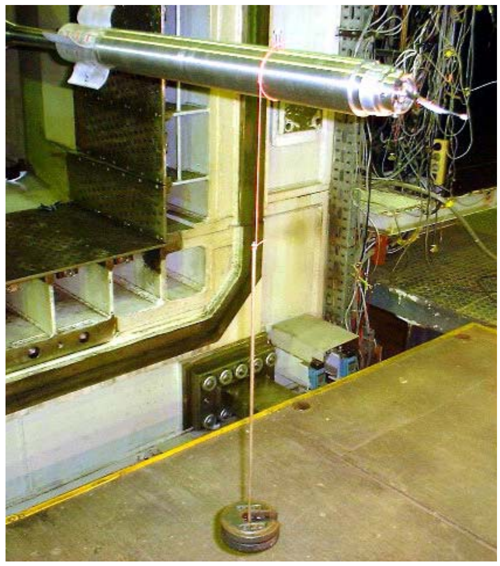

Figure 7. Calibration of one component transducer in the wind tunnel test section

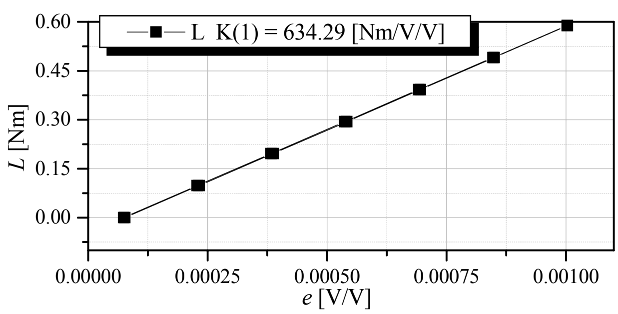

Figure 8. Calibration diagram

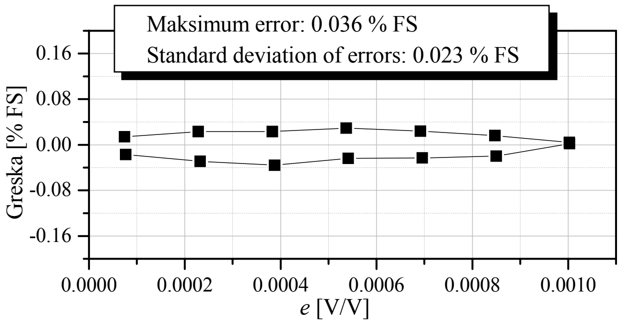

Figure 9. Error diagram

Table 1. Output signals from the measurement bridge

Ordinal number	Applied load L [Nm]	Theoretical value of output signals e [V]	Measured output signals e [V]
1	0.09806	9.229 · 10-4	9.168 · 10-4
2	0.19612	1.846 · 10-3	1.844 · 10-3
3	0.29418	2.769 · 10-3	2.769 · 10-3
4	0.39224	3.692 · 10-3	3.699 · 10-3
5	0.49030	4.615 · 10-3	4.630 · 10-3
6	0.58836	5.538 · 10-3	5.563 · 10-3

Measurement results

According to the test programme, twenty eight runs with one component transducer for measuring the rolling moment on the model MODEL01 have been done.

Table 2. Measurement results for M=1.75

Ordinal number	C_{l0}	Ordinal number	C_{l0}
1	0.0245	6	0.0250
2	0.0245	7	0.0248
3	0.0248	8	0.0247
4	0.0249	9	0.0250
5	0.0249	10	0.0248
C_l average value: 0.02479			
Average error: 0.000134			
Standard deviation: 0.00017			

In order to establish the repeatibility and accuracy of the rolling moment measurement, ten runs for Mach number *M*=1.75 have been done. Results of these ten runs (model with wrap around wings) are presented in Table 2.

Rolling moment measurement results for 9 runs on the missile model with wrap around wings are presented in Table 3 and Fig.10.

Table 3. Measurement results (wrap around wings)

Ordinal number	M	C_{l0}	Ordinal number	M	C_{l0}
1	0.495	0.0062	6	1.384	0.0176
2	0.675	0.0072	7	1.485	0.0191
3	0.899	0.0068	8	1.737	0.0245
4	1.007	0.0113	9	1.975	0.0393
5	1.103	0.0161			

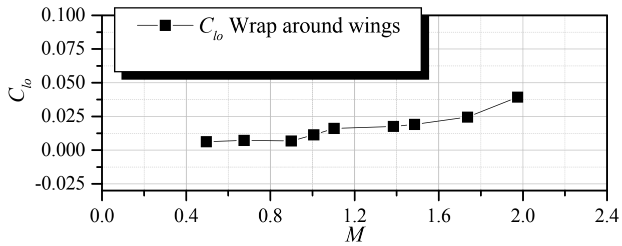

Figure 10. Rolling moment measurement results on the missile model with wrap around wings

Rolling moment measurement results for 9 runs on the missile model with rectangular wings are presented in Table 4 and Fig.11.

Table 4. Measurement results (rectangular wings)

Ordinal number	M	C_{l0}	Ordinal number	M	C_{l0}
1	0.495	0.0316	6	1.383	0.0201
2	0.674	0.0326	7	1.484	0.0204
3	0.899	0.0323	8	1.736	0.0300
4	1.007	0.0301	9	1.975	0.0345
5	1.100	0.0291			

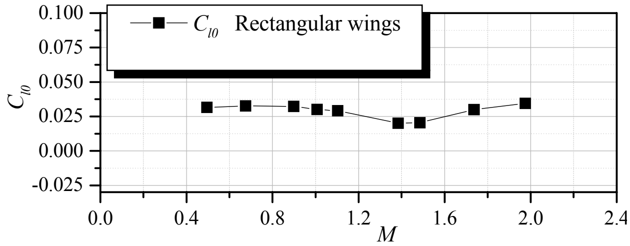

Figure 11. Rolling moment measurement results on the missile model with rectangular wings

Conclusion

Description, design, calibration and measurement results of one component transducer for measuring the rolling moment are presented in this paper. Measured output signals during calibration compare well to the theoretical value of the output signals of the measuring bridge. Accuracy of the transducer is 0.02% of the nominal load range. During calibration and measurement in the wind tunnel T-38 this one component transducer is indicated as highly reliable, quality measuring equipment which will be in use in the future experiments in the laboratories of experimental aerodynamics.

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Jednokomponentni davač za merenje momenta valjanja na modelu rakete

U radu je dat opis specijalno konstruisanog jednokomponentnog davača za merenje momenta valjanja na modelu rakete. Merni opseg davača je 1 Nm, a tačnost 0.02% mernog opsega, što je deset puta veća tačnost od tačnosti do sada korišćenih aerovaga. Tokom eksperimenta davač se pokazao kao veoma pouzdano merno sredstvo koje će se koristiti u laboratorijama eksperimentalne aerodinamike

Ključne reči: **aerodinamički tunel, jednokomponentni davač, model rakete, moment valjanja eksperimentalna aerodinamika.**

Однокомпонентный датчик для измерения момента крена на модели ракеты

В настоящей работе приведено описание специально конструированного однокомпонентного датчика для измерения момента крена на модели ракеты. Диапазон измерений датчика 1 Нм, а точность 0,02 % диапазона измерений, что представляет точность на десят раз больше от точности до сих пор пользованных аэровес. В течении эксперимента датчик показался весьма надёжным средством измерений, которое будет пользовано в лабораториях экспериментальной аэродинамики.

Ключевые слова: аэродинамическая труба, однокомпонентный датчик, модел ракета, момент крена, экспериментальная аэродинамика.

Le transducteur à une composante pour mesurer le moment de roulement du modèle de missile

La description d'un transducteur conçu spécialement pour mesurer le moment de roulement sur le modèle de missile est exposée dans ce travail. La portée du mesurement de transducteur est de 1 Nm, tandis que la précision du mésurement est 0,02%, ce qui représente une précision dix fois plus grande que chez les balances aériennes, utilisées jusqu'à présent. Pendant les essais, le transducteur s'est révélé comme un moyen de mesurement très sûr; il trouvera son emploi dans les laboratoires de l'aérodynamique expérimentale.

Mots clés:, **soufflerie aérodynamique, transducteur à une composante, modéle de missile, moment de roulement, aérodynamique expérimentale.**