

# FORCE MEASUREMENTS IN MAGNETIC SUSPENSION AND BALANCE SYSTEM

Alexander Kuzin  
Moscow Aviation Technological Institute  
Moscow, Russia

George Shapovalov  
Central Aero-Hydrodynamic Institute  
Moscow region, Russia

Nikolay Prohorov  
MERA LTD Company  
Moscow, Russia

## SUMMARY

The description of an infrared telemetry system for measurement of drag forces in Magnetic Suspension and Balance Systems (MSBS) is presented. This system includes a drag force sensor, electronic pack and transmitter placed in the model which is of special construction, and receiver with a microprocessor-based measuring device, placed outside of the test section. Piezosensitive resonators as sensitive elements and non-magnetic steel as the material for the force sensor are used. The main features of the proposed system for load measurements are discussed and the main characteristics are presented.

## INTRODUCTION

Experimental aerodynamicists extensively test aircraft models in wind tunnels. The behavior of models in a confined flow with specified parameters indicates how a real aircraft will behave in flight. Similarity to real conditions is thus of paramount importance in an aerodynamic experiment. The mechanical components (strings, tension members, struts, etc.) used to support the models block the wind tunnel and disturb the airflow. Assessing the effects they have on the experimental results is extremely difficult because of their diversity and ambiguity. Thus, support systems that do not disturb the airflow in the wind tunnel are stiff and yet accurately transmit the aerodynamic loads borne by the model to measurement devices. These requirements are met by magnetic suspension and balance systems [1]. The mechanical connections are

replaced by the forces in the electromagnetic field, and all mechanical contacts with the suspended object are completely removed while the potential for accurate measurement is retained.

Most aerodynamic experiments are aimed at determining the aerodynamic forces and moments on the model. They are derived from the electromagnetic forces and moments counterbalancing them. The electromagnetic forces and moments are determined by the currents in the electromagnets and the model's spatial coordinates relative to the electromagnets. Only the currents and the model coordinates can be measured directly. To find the aerodynamic forces and moments, the relationship between the electromagnetic forces, the currents, and the model coordinates must be established. Since this relationship is hard to calculate with the required accuracy (which is determined by the accuracy of measuring the aerodynamic loads) it has to be established experimentally (from a calibration procedure).

Traditionally, the aerodynamic loads are derived from the variations in the currents in the windings of the corresponding magnets. These currents are automatically regulated to balance the aerodynamic forces and to hold the model at a constant static position. The calibration procedure involves loading the model with a known external load close to that expected (Figure 1) and measuring the currents in the electromagnets with no airflow past the model.

To automate the process and to decrease the calibration measurements, some mathematical relation between the magnetic forces (or moments) and the currents is assumed. Based on certain assumptions, it could be the squared form:

$$P_{qm} = \frac{1}{2} \sum_{k=1}^n \sum_{s=1}^n \frac{\partial L_{ks}}{\partial q} i_k i_s, \quad (1)$$

where  $P_{qm} = \{ F_{xm}, F_{ym}, F_{zm}, M_{xm}, M_{ym}, M_{zm} \}$  are magnetic forces and moments;  $q = \{ x, y, z, \gamma, \psi, \theta \}$  are coordinates of the model;  $L_{kk}$  - inductance of electromagnet ( $k=1, \dots, n$ );  $L_{ks} = L_{sk}$  - mutual inductances of electromagnets;  $i_k$  is the current in the k-th electromagnet;  $n$  is the number of electromagnets.

With other assumptions, the relation between the magnetic forces and currents could be described as linear:

$$P_{qm} = \sum_{k=1}^n A_{qk} (i_k - i_{k0}), \quad (2)$$

where  $A_{qk} = \left( \frac{\partial P_{qm}}{\partial i_k} \right)_{i_0, \theta_0}$ ;  $i_{k0}$  is the initial current in the k-th electromagnet (that is

required to support the model when there is no load).

An adequate way of finding the calibration relations (for example, for linear relation (2)) is to load the model with  $n$  values of the multicomponent load, measure the currents in every electromagnet for each value of the load, and to solve the system of  $n$  equations linear in unknowns  $A_{qk}$ .

During wind-tunnel tests of a model, the currents in the electromagnets are measured and the acting aerodynamic load is found from the calibration relations.

To improve MSBS calibration, it has been proposed [1] that intra-model strain gauges be used which, in the absence of airflow, would be suspended in the magnetic field together with the model; known load components are applied to the balance through the calibration rod. One end of the balance is fastened to the model and the calibration rod is attached to the other end.

A promising modification of this method is to use an intra-model strain-gauge balance to measure the aerodynamic loads in MSBS wind-tunnel tests. This technique will eliminate calibration of the MSBS system which is time-consuming and requires complicated equipment. The MSBS is then used only to support the model. The challenge is to get contactless transmission of the signals carrying information of the loads being measured by the intra-model balance from the model to the detection and processing equipment. Investigation of that problem is the subject of this paper.

## SYSTEM DESCRIPTION

A schematic of the drag force measurement telemetry system is shown in Figure 2. A model of special construction was developed to house the telemetry package and measure drag force. The model consists of a non-magnetic housing and magnetic core that is connected with the housing through two bars of non-magnetic steel. One of these bars is the force sensor (product of Mera LTD). The model is placed in a wind tunnel and its position is stabilized because of the interaction of the core with an automatically controlled magnetic field generated by magnets situated outside the test section. When the external force is applied to the model in the  $x$  direction, the force sensor is in a strained condition because the external force is applied to the non-magnetic housing of the model, but the magnetic force is applied to the magnetic core of the model. Construction of the force sensor is shown in Figure 3. Two piezo-sensitive resonators are placed on the surface of the bar by means of elastic glue. One of the resonators is in the strained condition under load and the other one is in a compressed condition. Construction of the force sensor removes the influence of applied moments on the measurement result. The resonators are chosen in such a way that the differences between their resonance frequencies is equal to 2-7 KHz and the first one has a working frequency in normal condition (without load) about 10 Mhz. Each of the resonators is included in a generator circuit. Figure 4 shows a schematic of the signal conditioner. The output signals of the generators are multiplied in a multiplier and then passed through a low-pass filter. The output signal of the filter is proportional to the difference between the resonance frequencies of the resonators. The resonant

frequency of each resonator linearly depends on the load, and the difference between their frequencies depends on the load also. The amplified signal, the frequency of which is proportional to the load force, feeds the infrared light emitting diode (LED). A frequency-modulated optical signal from the LED crosses the test section of the wind tunnel and is received by the silicon photodiode located outside the test section. The signal of photodiode is read by the microprocessor-based measuring device that transforms frequency into binary equivalent and shows the measured drag force on the indicator.

The power supply for the drag force measurement telemetry system is a battery of 8 V. The battery and conditioner pack are placed inside of the model housing. The LED is glued in the hole through the side of the model housing.

### CALIBRATION OF THE DRAG FORCE MEASUREMENT SYSTEM

The calibration procedure involves applying known loads to the force sensor at a constant temperature and measuring the frequency-modulated signal by the microprocessor-based measuring device connected with the photodiode. The calibration results are presented in Figure 5 and show that the output frequency of the force sensor linearly depends on load for constant temperature.

The effect of varying the battery voltage on the output frequency of the force sensor is presented in Figure 6 and shows that output frequency is independent of the battery voltage over a wide operational range. The application of a compact integral regulator of battery voltage will increase the operational time of the system.

The differential system of sensitive elements is thermally balanced. The thermal influence is 0.1% per  $1^{\circ}\text{C}$  of the maximum calibration load of 20 N.

### EXPERIMENTAL RESULTS

Figure 7 shows the MSBS at MAI-TsAGI [2] that was used for the drag force measurement experiment. The drag force measurements were taken for a model with a 400 mm length and 40 mm diameter over the velocity range from 0 m/s to 50 m/s. The results are presented in Figure 8. The experiment indicates good repeatability of two sets of measured data. The standard deviation of data from the mean is less than 1% of the maximum calibration load of 5 N. Figures 9 and 10 show the model that was used for drag force measurements.

### CONCLUSIONS

An infrared telemetry system for measurement of drag force in magnetic suspension and balance systems has been developed. The experimental results prove the possibility of application of the intra-model balance for contactless force measurements in MSBS. The construction technique can be developed for multicomponent force measurements.

## REFERENCES

1. Kuzin, A.V.: Electromagnetic Suspension Systems in Experimental Aerodynamics: State of the Art and Prospects. *Instruments and Experimental Techniques*, No. 3, 1992, pp. 403-416.
2. Kuzin, A. V.; Vyshkov, Y. D.; Shapovalov, G. K.: Progress of magnetic suspension and balance systems for wind tunnels in the USSR. Proceedings of International Symposium on Magnetic Suspension Technology, NASA CP-3152, 1992, pp. 65-74.

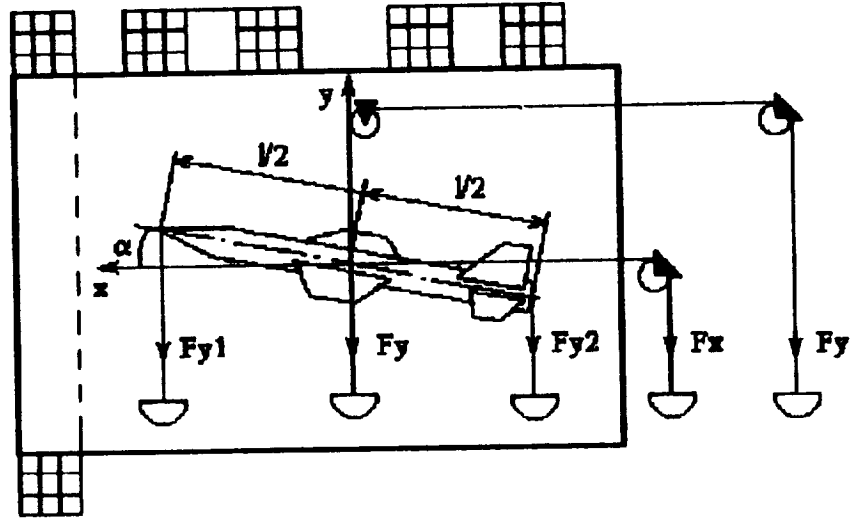


Figure 1. Calibration set-up of MSBS.

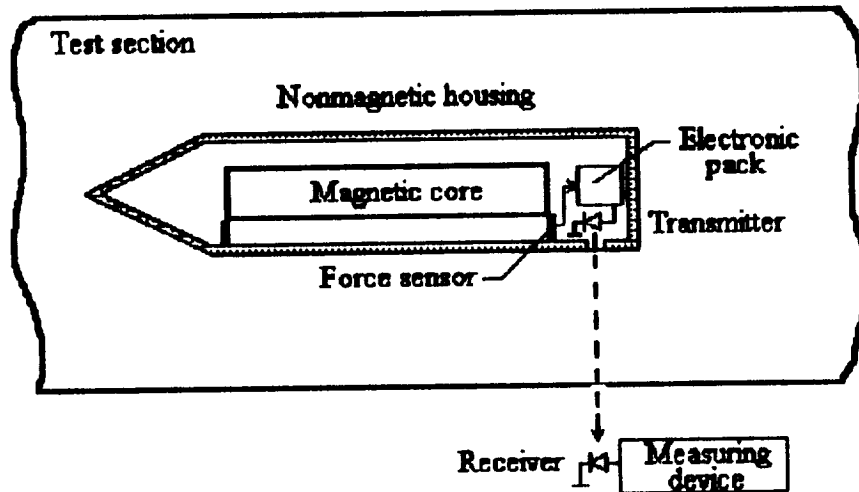


Figure 2. Schematic of drag force measurement telemetry system.

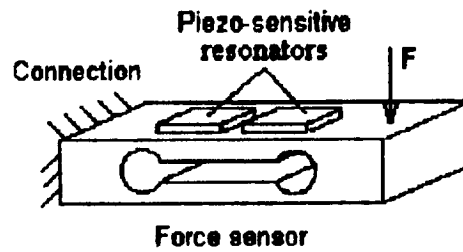


Figure 3. Construction of force sensor.

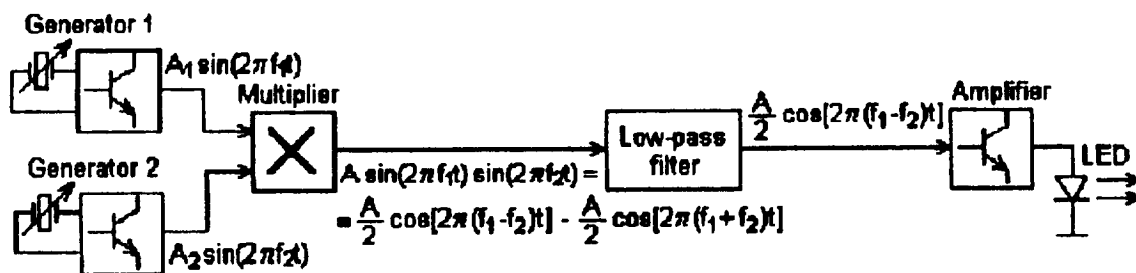


Figure 4. Schematic of signal conditioner.

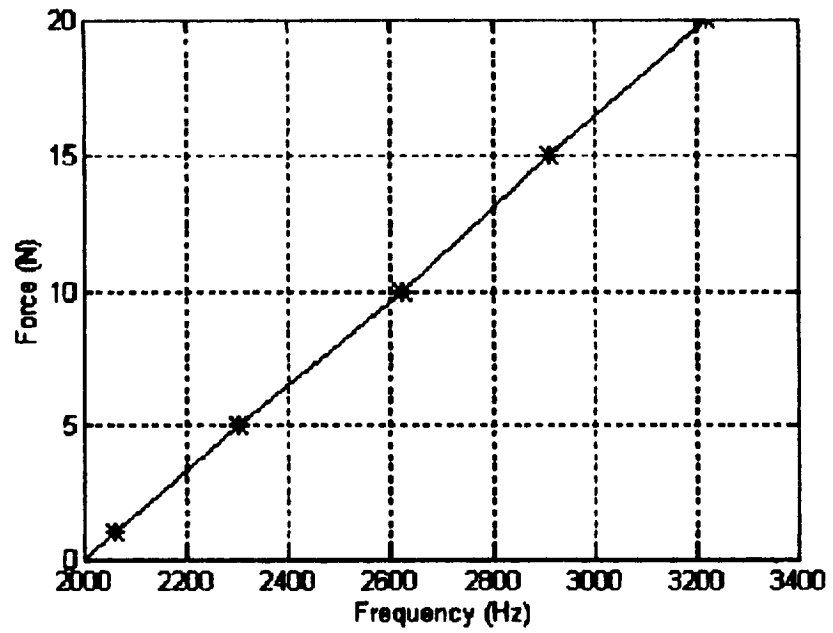


Figure 5. Drag force measurement telemetry system calibration curve.

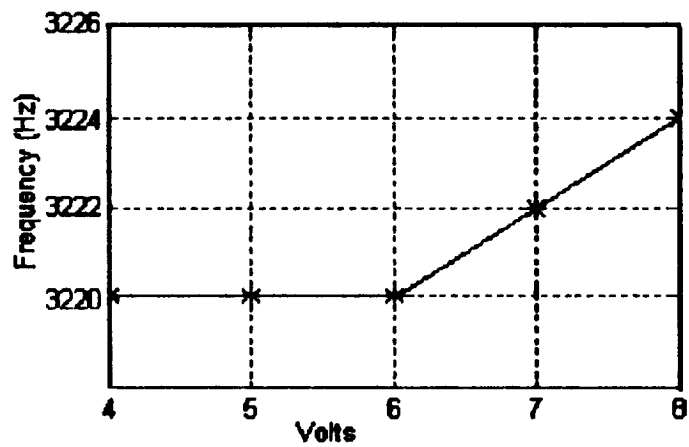


Figure 6. Effects of battery voltage on output frequency.



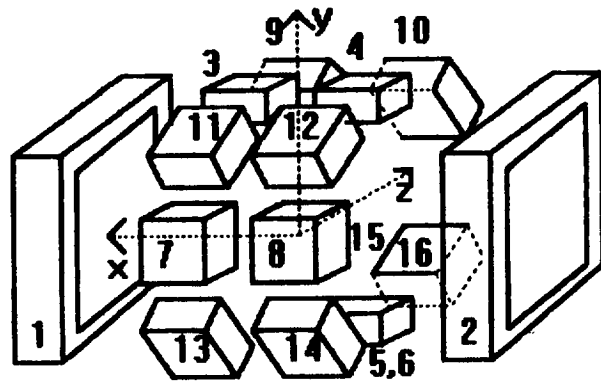


Figure 7. Magnetic Suspension and Balance System of MAI-TsAGI.

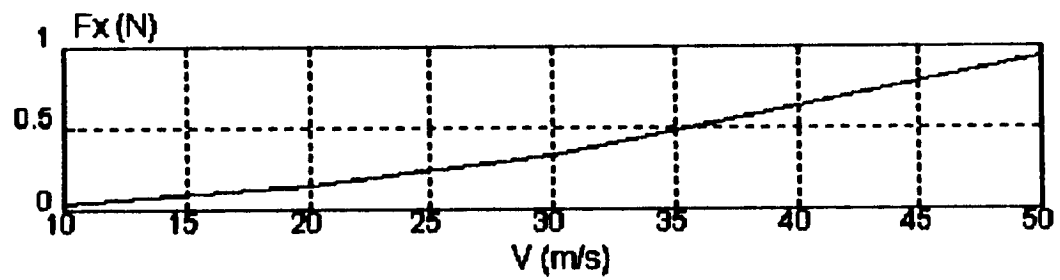


Figure 8. MSBS drag force measurements.



Figure 9. Photograph of model in magnetic suspension of MAI-TsAGI.

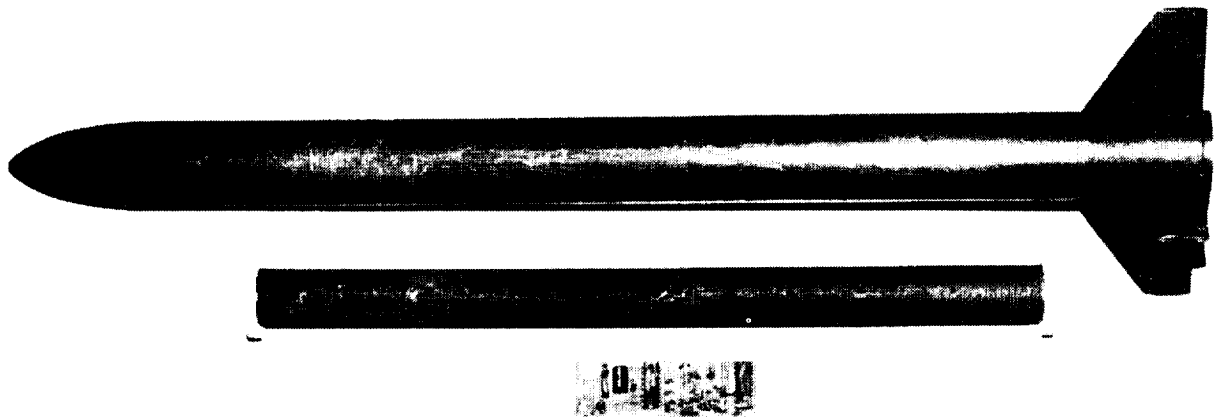


Figure 10. Photograph of model with telemetry system and magnetic core.

