

# NEW GENERATION PORTABLE DATA ACQUISITION SYSTEM

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## Abstract

*Aircraft flight testing is an extended branch of aerospace science and its development is closely related to the increasing requirements of the traffic safety.*

*Contemporary the prototype flight testing of a small aircraft does not include a flight measurement with a data recording because the cost of these measurements is not acceptable for companies building these kinds of aircraft. The result of this flight measurement is a data file containing very useful aircraft information for a designer. Knowledge of the flight behaviour and flight loads of a sport aircraft, a glider or an ultralight has got a positive influence on sport flying and soaring safety.*

*Looking on all the special requirements for small aircraft flight testing the development of a new portable data acquisition system (DAS 12) was started at the Institute of Aerospace Engineering of Brno University of Technology with the collaboration with Mesit ltd. The system should fully satisfy all the requirements.*

*DAS 12 is digital twelve-channel mobile data acquisition system dedicated for strain gauges measurements, pressure measurements, temperature and other analogue variable measurement.*

*Data acquisition system is created together with a sensor set. The sensors capture the movement of the aircraft from rolling until the landing.*

## 1. DAS - 12 system overview

The purpose of the DAS - 12 data measurement system is to accept both static and low frequency data outputs from various sensors used, in particular, in aircraft testing and to record and display these results on personal computer. Such sensors may range from a potentiometer or resistive strain gauge to a pressure transducer or accelerometer.

The system is programmable allowing the user to define the value of such parameters as type of input, excitation voltage or current, sample rate and gain. All users interaction with the system is through the software. During data acquisition the system supplies various modes of monitoring the real-time system performance, both graphic and alphanumeric and these displays are clear and easily read. Results can be saved in various formats for easy analysis.

### 1.1 Technical specification

Number of channels

- 12 per unit

Power Supply

- Battery Power Supply of 12V DC from internal battery for portable use
- External Power Supply of 240 V AC or 12V DC

Inputs per channel

- Full Bridge
- Potentiometer
- Half Bridge
- Quarter Bridge
- D.C. Voltage Input

Outputs per channel

- Excitation voltage 0 to 5V in steps of 10 mV
- Current 20mA in steps of 0,1 mA
- Excitation current and excitation voltage are set by computer program independently for every channel with an error less then 0,3 %

Software

- To run under Windows 95 or 98 on a personal computer

The DAS-12 system must interface with the computer trough the computer's parallel printer port. This implies the need for an interface board to connect the twelve measurement boards together and link them to the computer.

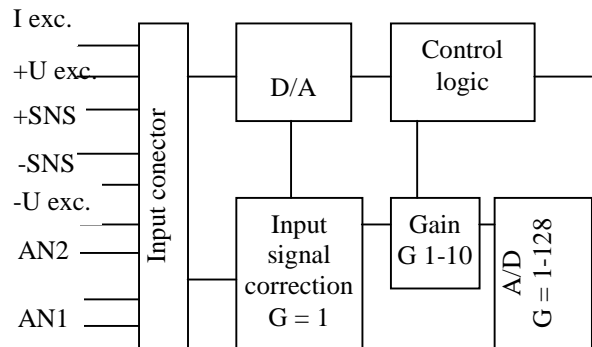
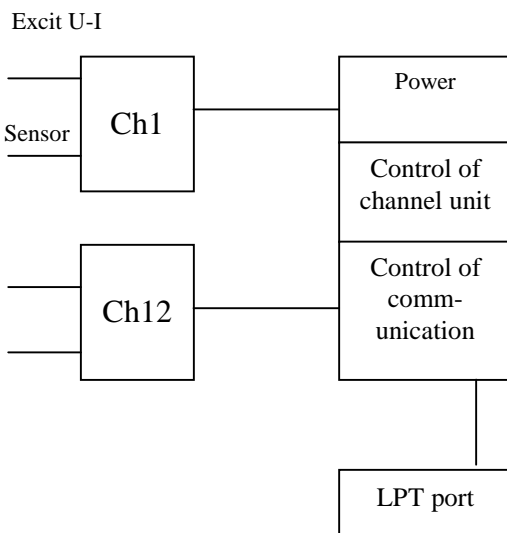


Fig. 1 DAS-12 block diagram

### 1.2 Measurement board

The measurement board is the heart of the DAS-12 system its overall purpose being to capture the "real world" input signal and converts it into a form the computer can understand. The design of the measurement board is based around two integral components: one analogue to digital converter (ADC) and one digital to analogue converter (DAC). The DAC performs the conversion of the computer's control signals into excitation voltages and currents and the ADC converts the analogue input signal into a digital pulse stream to be fed into the computer. The connection between the measurement board and the interface board is made by via a 16-way ribbon cable with IDC connectors.

### 1.3 Software

The DAS-12 software, written using the client/server suite Delphi Pro to run under Windows 95 or 98, controls all system functions. There are four main parts to the software: "Configuration", "Graph", "Data" and "Calibration".

#### 1.3.1 Configuration section

The main function of the "configuration" section of the software is to set up all variables for each channel. The configuration screen is shown in figure 1, the main parts of which been clearly labeled.

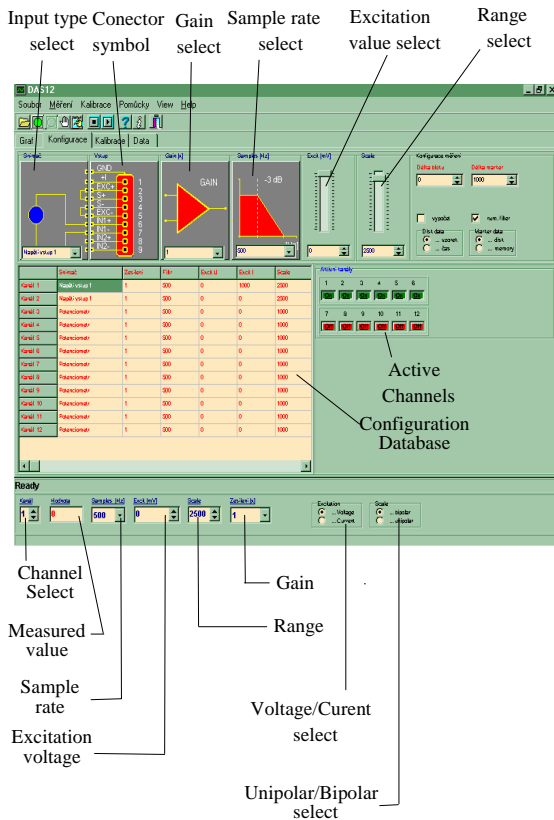


Fig. 2 "Configuration" screen

The "Channel Set-up" part of screen is used to select the type of input, gain, sample rate, excitation voltage/current value and range for each channel. This is done using the drop down list menus or value selection boxes. In the case of excitation value and range, these can also be selected using the appropriate slide controls. A pictorial representation of the input configuration will also automatically appear giving the user a quick and easy way of checking the set up for that channel.

The excitation voltage and current ranges available are as given in technical specification. Range can vary from  $\pm 100$  to  $\pm 30000$  in steps of 1 and the following sample rates are available: 5, 10, 25, 30, 50, 60, 100, 250 and 1000 Hz. Gains of 1 to  $2^n$ ,  $n = 1, 2, \dots, 7$ , can be selected. For full bridge gain will be 10 times  $2^n$ , for voltage inputs gain will be  $2^n$  and for other inputs gain will be 5 times  $2^n$ .

The current channel is selected using the "Channel Select" box in the bottom status bar, which is present in every section: Configuration, Graph, Data and Calibration. Excitation voltage or current and unipolar or bipolar scale are also chosen in the bottom status bar. In addition, sample rate, excitation value, range and gain can also be set here.

The "Configuration Database" shows the set up for each channel. Values also can be edited here. The "Active Channels" box is used to select which channels are off and which are on.

When the program is exited, the last set of channel configuration options is remembered.

### 1.3.2 Graph section

The "Graph section is used to keep track of the real-time operation of the system. Two different types of graph are available. The first is selectable, rather confusingly, by the "Graph" tab and gives a display for one channel only, similar to that of an oscilloscope, with the graph scrolling along.

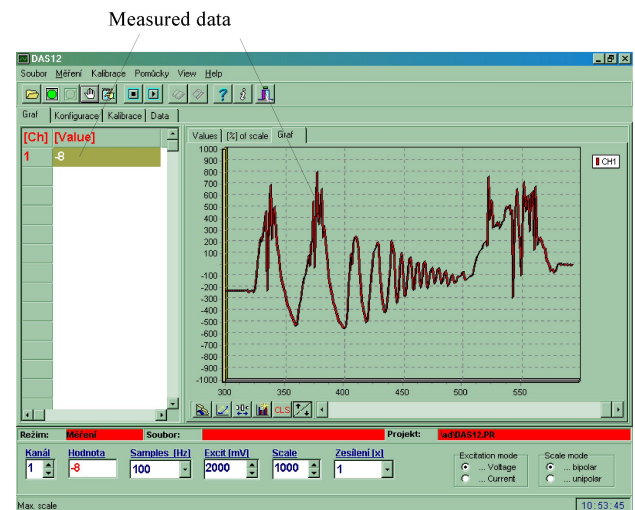


Fig. 3 "Graph" screen

### 1.3.3 Database section

The "Database screen is used to display results, both graphically and alphanumerically, as they are written to a database file. Results for each sample instant for each channel are saved to the file. This can then be used to load results into a spreadsheet. The database itself is displayed on this screen as are each channel value and the same chart as displayed in the "Graph" section.

### 1.3.4 Calibration section

The "Calibration" section is used to set calibration for each channel. There is a graph of range percentage to zero calibration.

### 1.3.5 Obtaining results

After configuring each active channel, measurement can be started by choosing "Start" from the "Measurement" menu or by clicking the green spot on the top status bar. Stopping the measurement is achieved by choosing "Stop" menu or by clicking the red spot on the top status bar. If any variable is changed in the configuration set up, the measurement is automatically stopped. If only one or more sampled measurement is required, either choose "Sample" from the "Measurement" menu or click the hand symbol on the top status bar.

The "File" menu is used to open and close database files as well as text files should the user wish to save results in ASCII format. If a database or text file is open, results are automatically written to it when the measurement is started. The "File" menu is also used to open or close projects. A project is simply a list of channel configurations should the user wish to use the same setting on more than the occasion.

Calibration is carried out through the "Calibration" menu. Two types of calibration are available at the moment. The first is "System calibration" which effectively resets the ADC for a new input type. The second is "Input zero calibration" which removes any offsets when the sensor is in "zero output state. Calibration can also be selected for only one channel or for all channels.

## 2 Communication between hardware and software

There are two stages in the communications between the hardware and software. The first is the initialization procedure that is carried out every time a measurement is started. This sets up the hardware for the particular input, the excitation voltage or current, gain, sample rate and so on. The sample rate must be the same for each measurement board and the software is written such that this is the case: if the sample rate is changed for one channel, it changes to the same value for all channels. In this design where data to and from each measurement board travels down the same bus lines, it would be extremely difficult to get the timing right so as to allow different sample rates. The second stage is the read procedure which reads the data from each measurement board in turn into the computer.

## 3 Development and testing

During its development, the system was constantly tested in order to determine whether each upgrade, modification or addition to either the software or hardware had been made successfully and that it was functioning as expected. The results of these tests were used to aid further development of the system and to correct any faults. This could mean either some simple debugging or even a design rethink.

The measurement board was connected to the prototype interface board which, in turn, was connected to the computer and to the power supply. Firstly, the excitation voltage was measured at the output of the measurement board and compared to the expected value displayed on the computer screen. This was found too much.

The first input to be tested was that of the potentiometer. An excitation voltage of 1250mV was used together with a scale of  $\pm 1000$ . The result of this test showed the system to operate as expected. With the potentiometer wound fully anti-clockwise, the value displayed by the software was -1000. As the potentiometer was turned clockwise this value increased until

it reached +1000 in the fully clockwise position. This test was repeated with the software set to "half bridge" with the same, correct result being obtained. Similar tests were made with full bridge and accelerometer in voltage input with successful results.

### 3.1 Error budget

The final test carried out on the system was an error budget on the excitation voltage and excitation current. The specification states that the actual excitation voltage or current appearing at the output of the measurement board should agree to within 0,3% of the selected value displayed on the computer screen.

The table 1 displays the results obtained when testing excitation voltage for the two measurement board. As this table shows, the percentage error in both boards is only less then 0,3% for excitation voltages above or equal to 400mV. The percentage error decreases to an acceptably low value, however, as the excitation voltage increases towards 5000mV. In order to detect the source of the error at the low excitation values, the output was measured directly from the VOUT pin of the digital to analogue converter. This was found to agree with the value EXCIT+ output confirming the error to be in the DAC.

Table 2 contains the results obtained when testing excitation current. As this table shows, excitation current is selected far more accurately the excitation voltage and agrees to within 0,3% for all except a few very low values of no more then 3mA. In the case of the second measurement board, many measured values obtained are exactly as expected with 0% error.

| Theoretical exc. volt. (mV) | Measurement board 1      |                      | Measurement board 2      |                      |
|-----------------------------|--------------------------|----------------------|--------------------------|----------------------|
|                             | Measured exc. volt. (mV) | Percentage error (%) | Measured exc. volt. (mV) | Percentage error (%) |
| 0                           | 0,4                      | -                    | 0,3                      | -                    |
| 100                         | 97,8                     | 2,20                 | 98,6                     | 1,40                 |
| 200                         | 198,2                    | 0,90                 | 199,2                    | 0,4                  |
| 400                         | 398,8                    | 0,3                  | 399,7                    | 0,08                 |
| 700                         | 699,4                    | 0,09                 | 700,3                    | 0,04                 |
| 1000                        | 1000,4                   | 0,04                 | 1001,3                   | 0,13                 |
| 1500                        | 1501,1                   | 0,07                 | 1501,4                   | 0,09                 |
| 2000                        | 2003                     | 0,15                 | 2003                     | 0,15                 |
| 2500                        | 2502                     | 0,08                 | 2501                     | 0,04                 |
| 3000                        | 3004                     | 0,13                 | 3003                     | 0,1                  |
| 3500                        | 3504                     | 0,11                 | 3503                     | 0,09                 |
| 4000                        | 4005                     | 0,13                 | 4004                     | 0,10                 |
| 4500                        | 4507                     | 0,16                 | 4505                     | 0,11                 |
| 5000                        | 5006                     | 0,12                 | 5003                     | 0,06                 |

Tab. 1 Excitation voltage error budget

| Theoretical exc. curr. (mA) | Measurement board 1      |                      | Measurement board 2      |                      |
|-----------------------------|--------------------------|----------------------|--------------------------|----------------------|
|                             | Measured exc. curr. (mA) | Percentage error (%) | Measured exc. curr. (mA) | Percentage error (%) |
| 0                           | 0,0003                   | -                    | 0,0001                   | -                    |
| 1                           | 1,0041                   | 0,41                 | 1,0017                   | 0,17                 |
| 2                           | 2,01                     | 0,5                  | 2,01                     | 0,5                  |
| 3                           | 3,01                     | 0,33                 | 3,00                     | 0                    |
| 4                           | 4,01                     | 0,25                 | 4,00                     | 0,00                 |
| 5                           | 5,01                     | 0,02                 | 5,00                     | 0,00                 |
| 8                           | 8,01                     | 0,12                 | 8,00                     | 0,00                 |
| 10                          | 10,01                    | 0,10                 | 10,00                    | 0,00                 |
| 12                          | 12,01                    | 0,08                 | 12,01                    | 0,08                 |
| 15                          | 15,02                    | 0,13                 | 15,00                    | 0,00                 |
| 18                          | 18,01                    | 0,06                 | 18,00                    | 0,00                 |
| 20                          | 20,01                    | 0,05                 | 19,99                    | 0,05                 |
| 22                          | 22,01                    | 0,05                 | 22,00                    | 0,00                 |
| 24                          | 24,01                    | 0,04                 | 24,00                    | 0,00                 |

Tab. 2 Excitation current error budget

## 4 Using in practice

### 4.1 Measurement of loads in flight

The measurement of loads on aircraft in flight is required for a variety of purposes such as in research investigations, structural integrity demonstration and development flight testing. A very useful tool for the measurement of the loads on aircraft structures is the strain gages. Properly installed and calibrated, such gages



may be to determine the structural loads on control surfaces, landing gear, wing, fuselage structures and other assemblies.

In our case we interested in a stabilizer loads of the KP2-U Sova ultralight aircraft. This stabilizer was intended to laboratory purpose. In first stage was a need to find suitable places for the strain gauges. Total six strain gauges was for torque moment and shear installed as shows a figure 3.

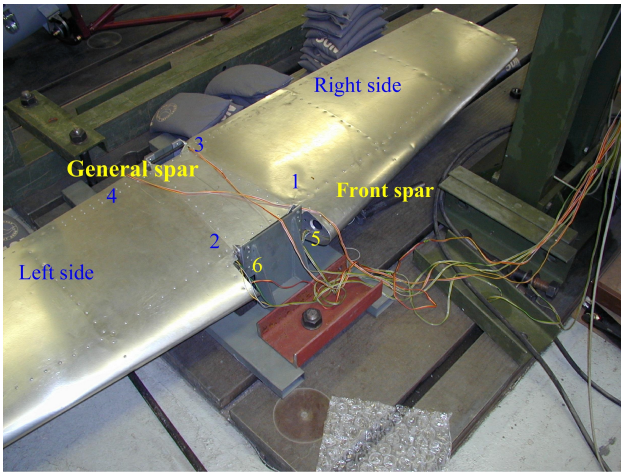


Fig. 4 Placing of strain gauges

The relation between the output  $m$  of strain gauge and the loads (in this case shear and torque moment) can be expressed by the equation:

$$\begin{Bmatrix} T \\ M_K \end{Bmatrix} = \begin{bmatrix} b_{11} & b_{12} & b_{13} & \cdot & \cdot & \cdot & b_{16} \\ b_{21} & b_{22} & b_{23} & \cdot & \cdot & \cdot & b_{26} \end{bmatrix} * \begin{Bmatrix} m_1 \\ m_2 \\ m_3 \\ \cdot \\ \cdot \\ m_6 \end{Bmatrix} \quad (1)$$

Where

- $T$  shear
- $M_k$  torque moment
- $b$  calibration coefficients
- $m$  bridges responses

If is torque moment and shear known, then values of load coefficient  $b$  are determined by solution of equation:

$$\|b_{ij}\| = \| \|m_{nj}\|^T * \|m_{nj}\|^{-1} * \|m_{nj}\|^T * \|T_n'\| \quad (2)$$

Where  $n$  is a number of loading

A similar equation can be written for torque moment.

Procedure of loading structure was following:

- left side 400N and 800N in two places on front spar
- left side 400N and 800N in two places on general spar
- right side 400N and 800N in two places on front spar
- right side 400N and 800N in two places on general spar
- all sides 400N and 800N on front spar, then general spar
- all sides at on time 400N in two places on front and general spar

It was made 13 measurement total and matrix of responses was  $6 \times 13$ . For all loading cases was calculated torque moment. Matrix of applied loads and bridge responses is in table 3 and 4.

| Applied loads Shear [N] |            | Applied loads Torque moment [Nmm] |        |
|-------------------------|------------|-----------------------------------|--------|
| Left side               | Right side | Mkr                               | Mkl    |
| 400                     | 0          | 0                                 | 146000 |
| 800                     | 0          | 0                                 | 292000 |
| 400                     | 0          | 0                                 | 0      |
| 800                     | 0          | 0                                 | 0      |
| 0                       | 400        | 146000                            | 0      |
| 0                       | 800        | 292000                            | 0      |
| 0                       | 400        | 0                                 | 0      |
| 0                       | 800        | 0                                 | 0      |
| 400                     | 400        | 146000                            | 146000 |
| 800                     | 800        | 292000                            | 290000 |
| 400                     | 400        | 0                                 | 0      |
| 800                     | 800        | 0                                 | 0      |
| 800                     | 800        | 146000                            | 146000 |

Tab. 3 Matrix of loads applied

| Responses<br>[μm/m] |         |          |         |                 |                |
|---------------------|---------|----------|---------|-----------------|----------------|
| 1. Right            | 2. Left | 3. Right | 4. Left | 5. Right torque | 6. Left torque |
| 1,7                 | 120,2   | 0,6      | 15,0    | -2,3            | -63,8          |
| -5,5                | 233,8   | -1,8     | 14,0    | -4,7            | -149,7         |
| -22,8               | 44,8    | 10,1     | 114,4   | -16,3           | 12,2           |
| -40,3               | 80,8    | 34,5     | 251,2   | -24,3           | 33,2           |
| 81,6                | -1,0    | 65,1     | 35,9    | -42,0           | 5,3            |
| 187,0               | -3,2    | 112,9    | 53,1    | -50,0           | 5,9            |
| 26,2                | -22,8   | 185,3    | 61,1    | 58,2            | -1,3           |
| 47,6                | -45,4   | 378,9    | 87,7    | 99,0            | -13,5          |
| 104,0               | 109,0   | 50,6     | 42,3    | -38,3           | -52,9          |
| 195,4               | 246,0   | 90,0     | 53,3    | -71,9           | -139,5         |
| 29,6                | 34,4    | 168,6    | 156,3   | 35,5            | 22,7           |
| 52,8                | 62,2    | 356,2    | 341,7   | 73,3            | 21,1           |
| 113,2               | 145,4   | 230,0    | 208,3   | -17,3           | -31,5          |

Tab. 4 Matrix of bridge responses

Solution of equation (2) was obtained calibration coefficients as shows table 5.

| Left side<br>B1 | Right side<br>B2 | Mkl<br>B3 | Mkr<br>B4 |
|-----------------|------------------|-----------|-----------|
| -0,5193         | 3,2150           | 506,9     | 1099,0    |
| 3,2628          | 0,0322           | 30,2      | 91,4      |
| -0,0789         | 1,6155           | -1242,5   | -1033,1   |
| 1,9796          | 0,2350           |           |           |

Tab. 5 Calibration coefficients

The probable error of estimate of shear and torque moment values was obtained from equation:

$$P.E.(T) = 0,6745 \cdot \sqrt{\frac{\sum \varepsilon_v^2}{n - (q + 1)}} \quad (3)$$

Where

$\sum \varepsilon_v^2$  sum of squares of the residuals  
 n number of loads applied

q number of coefficients in calibration equation

The probable error of estimate shear and torque moments is in table 6.

|            | P.E.(T)<br>[N] | P.E.(Mk)<br>[Nmm] |
|------------|----------------|-------------------|
| Left side  | 15             | 11094             |
| Right side | 15             | 11332             |

Tab. 6 Probable error of estimate shear and torque moment

The probable error in any calibration coefficients is obtained from the probable error or estimate for the equation and from the terms on the principal diagonal of the matrix:

$$\begin{pmatrix} p_{11} & p_{12} & \cdot & \cdot & \cdot & p_{1j} \\ p_{21} & p_{22} & \cdot & \cdot & \cdot & p_{2j} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ p_{j1} & p_{j2} & \cdot & \cdot & \cdot & p_{jj} \end{pmatrix} = \left\| \mathbf{m}_{nj} \right\|^T * \left\| \mathbf{m}_{nj} \right\|^{-1} \quad (4)$$

The relation for the probable errors of **b** is:

$$\begin{pmatrix} P.E.(b_{11}) \\ P.E.(b_{12}) \\ \cdot \\ \cdot \\ \cdot \\ P.E.(b_{1j}) \end{pmatrix} = P.E.(V) * \begin{pmatrix} \sqrt{p_{11}} \\ \sqrt{p_{22}} \\ \cdot \\ \cdot \\ \cdot \\ \sqrt{p_{jj}} \end{pmatrix} \quad (5)$$

In the table 7 and 8 are probable errors of any calibration coefficients obtained from equation (4) and (5).

|           |            |
|-----------|------------|
| P.E.(B1)  | P.E.(B2)   |
| Left side | Right side |
| 0,0647    | 0,0644     |
| 0,0478    | 0,0475     |
| 0,0458    | 0,0456     |
| 0,0526    | 0,0523     |

**Tab. 7 Probable error calibration coefficients of shear**

|           |            |
|-----------|------------|
| P.E.(B3)  | P.E.(B4)   |
| Left side | Right side |
| 87,3      | 83,1       |
| 37,5      | 47,3       |
| 144,8     | 150,3      |

**Tab. 8 Probable error calibration coefficients of torque moment**

Now for shear of left side stabilizer is possibility to write equation:

$$T_L = (-0,5193 \pm 0,0647)m_{rf} + (3,2628 \pm 0,0478)m_{lf} + (-0,0789 \pm 0,0458)m_{rg} + (1,9796 \pm 0,0526)m_{lg}$$

Where indexes rf, lf, rg and lg denotes left or right side and front or general spar.

Similar equation is for right side and torque moment.

For the check of solution was stabilizer loaded twice again. First load applied responded a gust load and second load applied responded a manoeuvring load. Responses were measured and computed force was compared with real force as shows table 9.

| Load [N] |          | Error      |           |
|----------|----------|------------|-----------|
| Applied  | Computed | Deflection | Error [%] |
| 1500     | 1581,6   | 81,6       | 5,44      |
| 1500     | 1480,1   | -19,9      | -1,32     |

**Tab.9 Computed and measured loads**

This way was established method of calibration KP2-U Sova stabilizer.

Now on the real stabilizer from operate aircraft were installed strain gauges and was made similar calibration procedure. But in this time is not yet any results and any in flight measurement with the strain gauges.

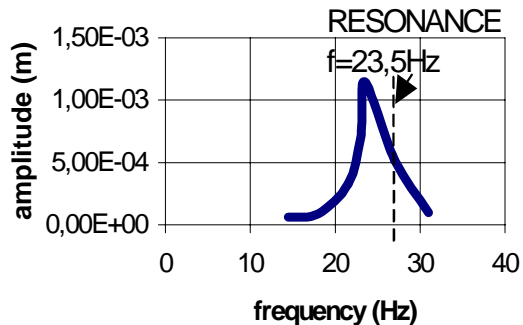
## 4.2 Ground vibration test

Other example of utilization of this data acquisition unit is the ground vibration test. For the testing of the system suitability for the vibration ground tests we have selected a stabilizer of the KP2-U Sova ultralight aircraft. For the first bending modal shape a simple shaker was developed. This shaker uses the phenomena of the rotating eccentric mass (driven by a small electric motor) as the generator of the exciting sinusoidal force. The shaker was fixed on the stabilizer tip rib closed to the elastic axe to excite the first bending mode. Moreover on the tip rib there was fixed an accelerometer ADXL05 which was connected with the DAS-12 unit. Description of the measure procedure is very simple, for the different angular exciter electric motor speeds we have measured and recorded the vertical acceleration on the tip of the stabilizer to determine the amplitude of the acceleration of the each exciter frequency. From this acceleration amplitude we can obtain the searched amplitude by a simple calculation:

$$amplitude_{position} = amplitude_{acceleration} / \omega \quad (6)$$

Now we can construct the graph of the dependence of the position amplitude on the frequency to find the system resonance frequency, which is the same with the first bending mode frequency.





**Fig. 5 Resonance curve for the first bending mode of the tested stabilizer**

## Conclusion

This paper has given an overview of the operation of the DAS-12 data acquisition system. In other parts of papers is shown using this system in practice as in flight data acquisition system and as system for a laboratory measurement of ground vibration. Now we have a possibility to measure any loads of aircraft structures or even load spectra.

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