The 3rd International Conference on "Computational Mechanics
and Virtual Engineering"
COMEC 2009
29 – 30 OCTOBER 2009, Brasov, Romania

MODAL TESTING OF A HELICOPTER BLADE

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Abstract: ***In this paper it is presented an experimental technique of modal parameters identification. There will be made a finite element modal model and there will be used data of damping factor obtained by experimental tests. At the end it will be propose a modal model of the considered blade based on theoretical and practical modal analysis.***

Keywords: modal analysis, modal parameters, experimental technique

1. INTRODUCTION

One of the main problems of mechanical structure subjected to dynamic loads is the identification of modal parameters, mass, damping and stiffness. These parameters can be found using some experimental procedures that are combined with theoretical aspects concerning specific relationships. A structure as a blade, in this case a stabilizing blade of a helicopter IAR 330, is a very complex one and the procedure of testing involve both, a free and forced response, to calculate the modal parameters. First it was considered the free response and then it was found the response under an impact hammer load. The structure was scanned and there was found the natural frequencies using the finite element method. The experimental data were recorded and processed using five accelerometers, type 4507 B, mounted on the blade with wax, the PULSE 12 Platform with associated soft, and the impact hammer type 8206-003, all produced by Brüel&Kjær company (Figure 1) [6]. Tests were conducted in the Modal Analysis Laboratory from the Strength of Materials and Vibrations Department, Transilvania University of Braşov [2,5].

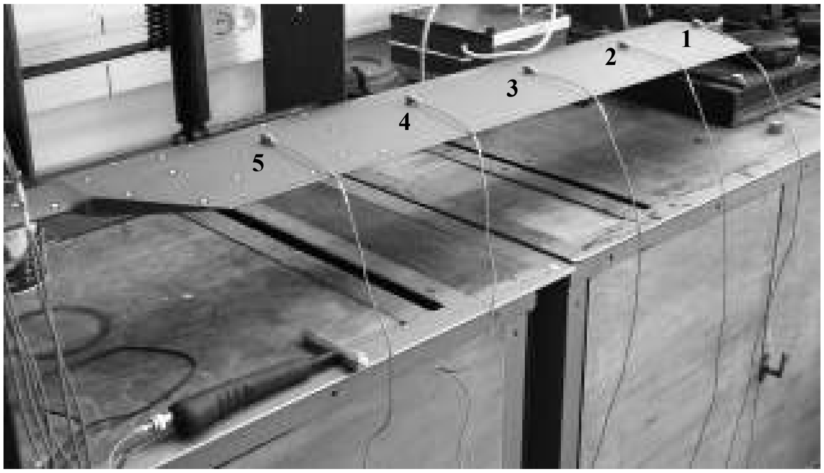
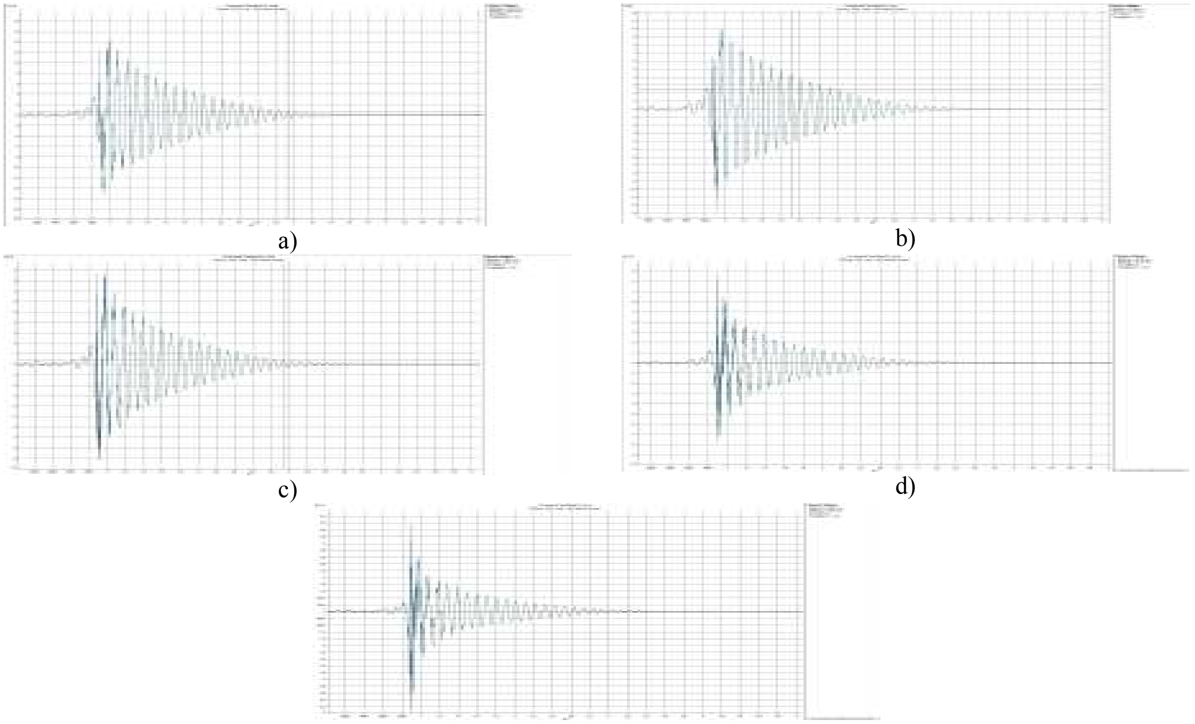


Figure 1: The fixed blade with the five accelerometers Brüel & Kjær 4507 B

2. STRUCTURAL FREE RESPONSE

The free damped response of the blade was analysed considering the blade fixed as in real case (Figure 1). The free damped response is obtained putting out of stable state (equilibrium position) the end of the blade (the end of the blade is pushed down) and then letting it free. The blade shape response, in all five measurement points, it is shown in

Figure 2, and the recorded pick values are presented in Table 1. Important to be mentioned is that in the frame of this test the blade is considered as a single degree of freedom system (SDOFS) with a mass, a damper and a spring.



a) b) c) d) e)

Figure 2: Blade response: a) accelerometer 1; b) accelerometer 2; c) accelerometer 3; d) accelerometer 4; e) accelerometer 5.

Table 1: The recorded acceleration values

Accelerometer 1		Accelerometer 2		Accelerometer 3		Accelerometer 4		Accelerometer 5	
Time [s]	Acceleration [m/s^2]	Time [s]	Acceleration [m/s^2]	Time [s]	Acceleration [m/s^2]	Time [s]	Acceleration [m/s^2]	Time [s]	Acceleration [m/s^2]
0.977	14.30	0,970	10,00	0,885	9,60	0,883	8,81	0,885	5,07
1.078	12.40	1,071	8,41	0,970	8,68	0,959	6,52	0,961	3,19
1.178	10.80	1,176	7,42	1,071	6,90	1,071	4,54	1,070	2,18
1.279	9.02	1,283	6,59	1,184	5,49	1,184	3,69	1,185	1,82
1.389	7.69	1,386	5,89	1,284	5,05	1,284	3,26	1,285	1,63
1.491	7.21	1,493	5,32	1,385	4,48	1,385	2,86	1,386	1,48
1.593	6.29	1,594	4,79	1,486	3,73	1,485	2,28	1,486	1,12
1.700	5.52	1,699	4,27	1,596	3,39	1,596	2,05	1,596	1,01
1.804	5.00	1,803	3,81	1,698	3,03	1,699	1,83	1,699	0,922
1.906	4.41	1,908	3,39	1,803	2,67	1,801	1,58	1,800	0,799
2.011	3.93	2,011	2,99	1,909	2,36	1,906	1,38	1,906	0,690
2.115	3.43	2,113	2,61	2,009	2,08	2,010	1,24	2,011	0,605
2.219	2.99	2,216	2,27	2,113	1,84	2,114	1,06	2,114	0,522
2.320	2.50	2,318	1,96	2,219	1,58	2,219	0,930	2,219	0,470
2.425	2.19	2,424	1,68	2,323	1,36	2,138	0,792	2,318	0,399
2.524	1.79	2,524	1,37	2,423	1,18	2,423	0,683	2,421	0,338
2.630	1.44	2,629	1,12	2,526	0,960	2,528	0,541	2,524	0,286
2.731	1.15	2,730	0,877	2,629	0,788	2,626	0,458	2,626	0,237
2.834	0.885	2,830	0,680	2,729	0,606	2,730	0,356	2,728	0,176
2.928	0.711	2,920	0,549	2,834	0,474	2,831	0,260	2,831	0,132

The mass of the blade was found direct by weigh oneself and it is $m = 2.8\,kg$. From recorded data (Table 1) results, for the blade considered as a SDOFS the following quantities that are useful in modal parameters identification are obtained [1,3,5]:

- The average free damped vibration period

$$T_d = 0.1\ [s] \qquad \textbf{(1)}$$

- The damped angular frequency

$$\omega_d = \frac{2\pi}{T_d}\ [rad/s] \qquad \textbf{(2)}$$

- The average damping decrement, considering the data recorded by all five accelerometers,

$$\Delta_{av} = \ln\left(\frac{A_i}{A_{i+1}}\right) = 0.15 \qquad \textbf{(3)}$$

- Average damping ratio

$$\xi = \frac{\Delta}{2\pi} = \frac{0.15}{2\pi} = 0.02 \qquad \textbf{(4)}$$

- Natural angular frequency

$$\omega_n = \frac{\omega_a}{\sqrt{1-\xi^2}} = \frac{62.83}{\sqrt{1-0.02^2}} = 62.84\left[rad/s\right] \qquad \textbf{(5)}$$

- Natural frequency

$$f_n = \frac{\omega_n}{2\pi} = \frac{62.83}{2\pi} = 9.99\left[Hz\right] \qquad \textbf{(6)}$$

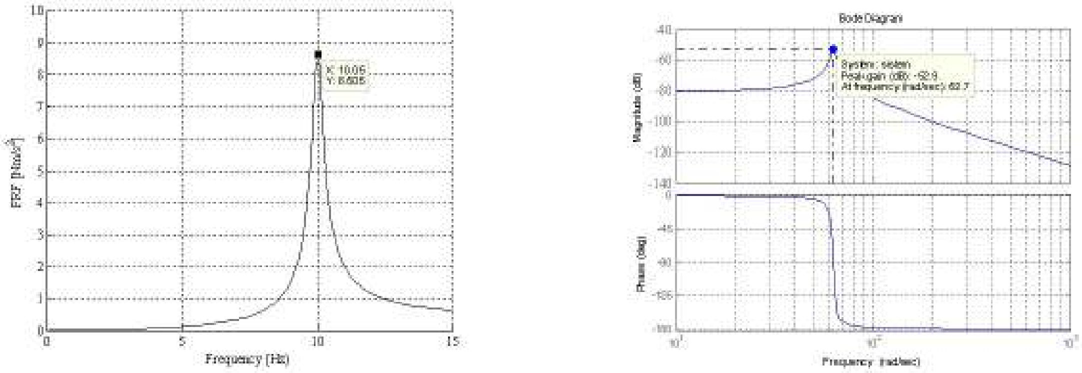
- Stiffness

$$k_{st} = \omega_n^2 m = 62.84^2 \cdot 2.8 = 11{,}032\left[N/m\right] \qquad \textbf{(7)}$$

Based on the above quantities data one can calculate the frequency response function (FRF)(Figure 2,a) [4]:

$$H(f) = \frac{1}{m}\frac{4\pi^2(m/k)f^2}{\sqrt{\left[1-4\pi^2(m/k)f^2\right]^2 + 4\pi^2(m/k)\left[c^2/(m\,k)\right]f^2}} \qquad \textbf{(8)}$$

and can plot the Bode diagram (Figure 2,b)



a) b)

Figure 3: Response blade as SDOF system a) frequency response function; b) Bode plot

3. IMPACT HAMMER TEST

Next step was to find out the modal response as a result of the impact hammer excitation. As is seen in Figure 1, it was used an impact hammer of type 8206-003 (Brüel&Kjær). There were considered three impact points (Figure 4). The recorded data are presented in the Figures 5 ÷ 7 [2, 6].

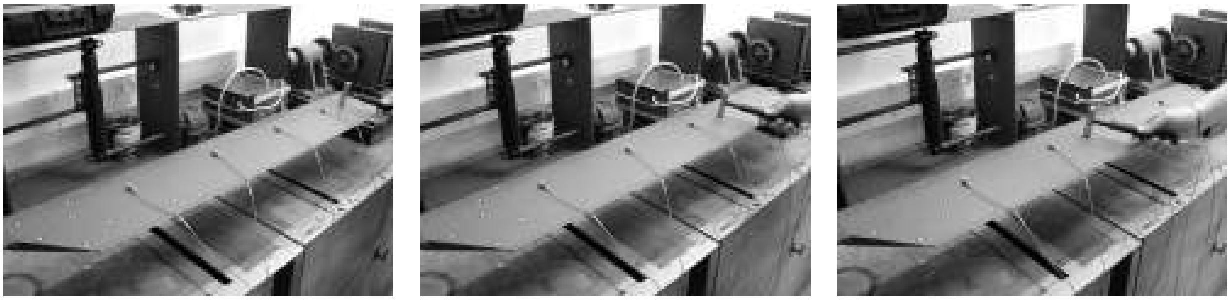

a) b) c)

Figure 4: a) first impact point; b) second impact point; c) third impact point.

3.1. The first impact point results

The first impact point was considered between accelerometers 1 and 2 (Figure 4,a). The blade frequency response shape, measured in all five points, is presented in Figure 5, and the recorded data are mentioned in Table 2.

Table 2: Acceleration recorded by all five accelerometers (the first impact point)

Frecquency [Hz]	Acc. 1 [mm/s^2]	Acc. 2 [mm/s^2]	Acc. 3 [mm/s^2]	Acc. 4 [mm/s^2]	Acc. 5 [mm/s^2]
10.00	597.00	455.00	311.00	173.00	85.10
30.00	6.53	5.58	5.33	4.49	2.97
45.00	59.50	12.80	29.00	50.80	48.90
82.50	62.80	7.88	52.80	50.60	12.10

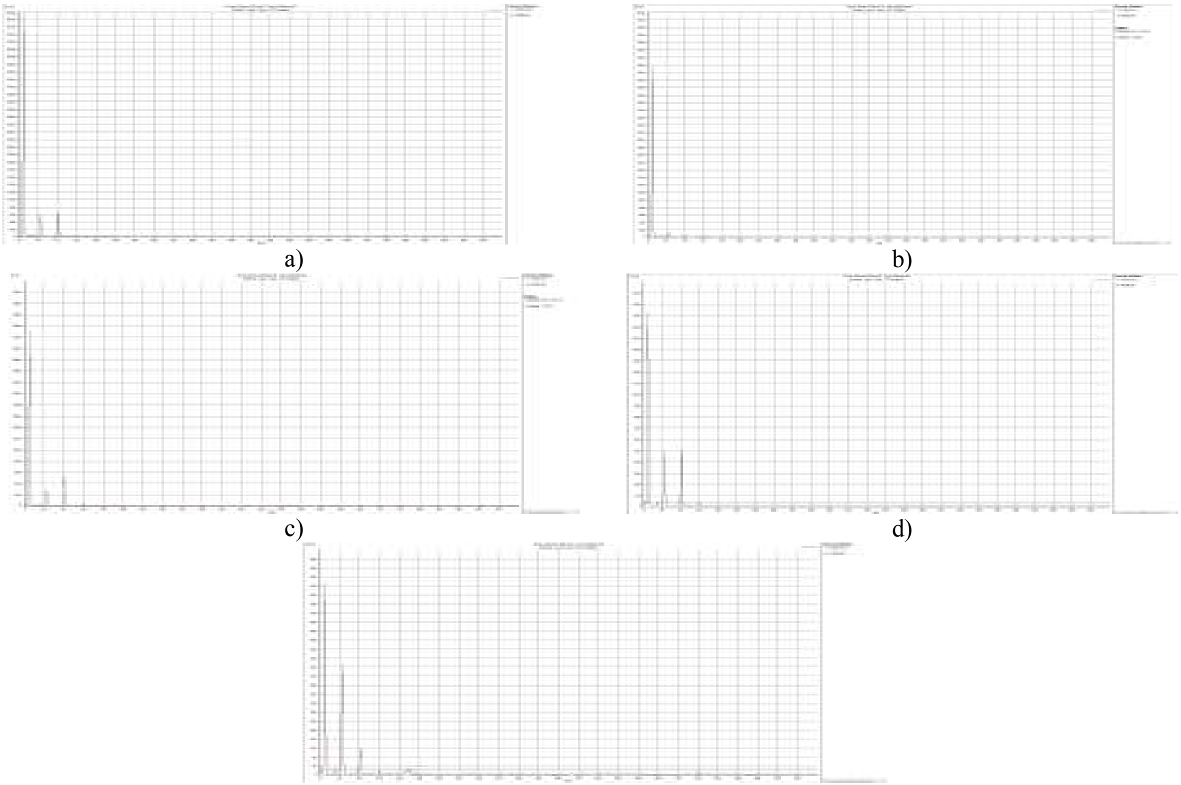

a) b) c) d) e)

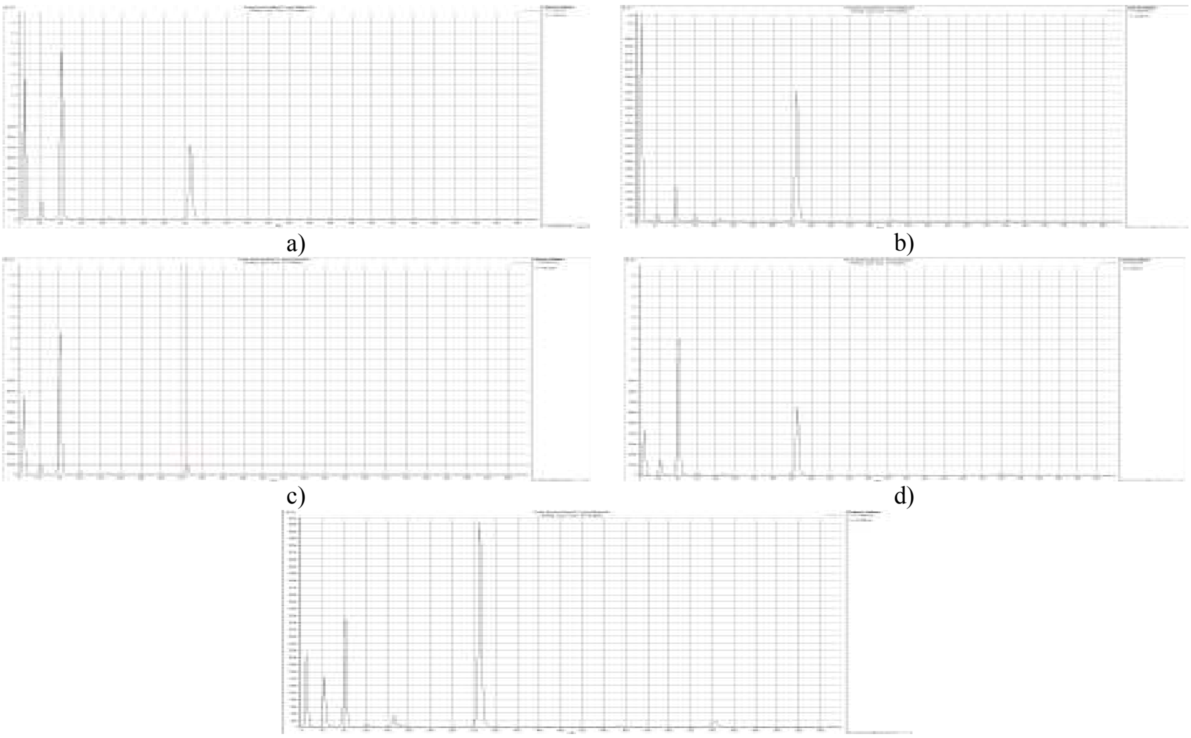
Figure 5: Blade frequency response as a result of the first impact hammer excitation: a) accelerometer 1; b) accelerometer 2; c) accelerometer 3; d) accelerometer 4; e) accelerometer 5; f) impact point.

3.2. The second impact point results

The second impact point was considered between the second and the third accelerometer (Figure 4,b). The blade frequency response shape, measured in all five points, is presented in Figure 6, and the recorded data are mentioned in Table 3.

Table 3: Acceleration recorded by all five accelerometers (the second impact point)

Frequency[Hz]	Acc. 1 [mm/s^2]	Acc. 2 [mm/s^2]	Acc. 3 [mm/s^2]	Acc. 4 [mm/s^2]	Acc. 5 [mm/s^2]
10.00	1440.00	1090.00	755.00	439.00	208.00
30.00	10.80	9.05	6.15	2.58	2.24
42.50	177.00	39.70	83.80	149.00	146.00
82.50	1620.00	188.00	1340.00	1300.00	310.00
120.00	21.00	34.80	34.10	22.60	9.29
172.50	32.40	22.20	29.40	12.60	34.60
330.00	722.00	686.00	93.90	654.00	587.00



a) b) c) d) e)

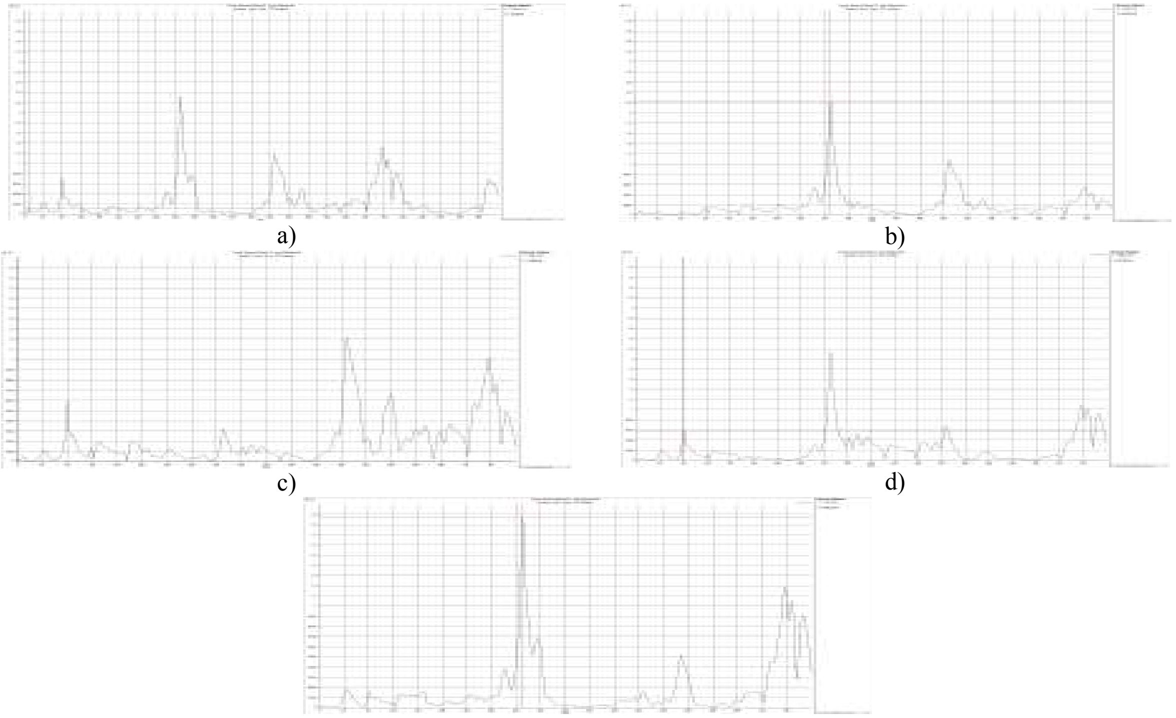
Figure 6: Blade frequency response as a result of the second impact hammer excitation: a) accelerometer 1; b) accelerometer 2; c) accelerometer 3; d) accelerometer 4; e) accelerometer 5.

3.3. The third impact point results

The third impact point was considered between the third and the forth accelerometer (Figure 4,c). The blade frequency response shape, measured in all five points, is presented in Figure 7, and the recorded data are mentioned in Table 4.

Table 4: Acceleration recorded by all five accelerometers (the third impact point)

Frecquency [Hz]	Acc. 1 [mm/s^2]	Acc. 2 [mm/s^2]	Acc. 3 [mm/s^2]	Acc. 4 [mm/s^2]	Acc. 5 [mm/s^2]
10.00	113.00	86.50	47.20	31.20	16.50
30.00	46.80	23.80	16.20	13.70	9.80
42.50	224.00	59.10	103.00	174.00	165.00
82.50	556.00	65.40	455.00	458.00	134.00
120.00	127.00	134.00	116.00	93.80	44.30
172.50	72.70	73.20	78.50	81.40	108.00
330.00	2320.00	2230.00	315.00	2120.00	1870.00



a) b) c) d) e)

Figure 7: Blade frequency response as a result of the second impact hammer excitation: a) accelerometer 1; b) accelerometer 2; c) accelerometer 3; d) accelerometer 4; e) accelerometer 5.

3. CONCLUSION

In the current work, there were presented two methods, the free damped response identification and the standard modal test with impact hammer, to find the fundamental natural frequency of a composite helicopter blade. Based on the recorded data one can make the following remarks:

- The calculated natural frequency, in the case of considering the blade as a classical dumped SDOFS with lumped mass, damper and spring and free response regime, was, relationship (6), $f_1 = 9.99\left[Hz\right]$;
- The modal tests point out that the frequency $f = 10\left[Hz\right]$ is presented, in all three cases of excitation, as fundamental frequency;
- In the same time, based on the modal tests in the second and third impact points, there were emphasized other natural frequencies (Tables 3 and 4). These frequencies are associated with the composite structure of the blade. As it can be seen, the shape response in the third impact point (Figure 7) is strong influenced by the stiffness of the blade that is structurally highly near the connection point.

Modal testing can provide valuable information about the dynamic response characteristics of bladed at a relatively low cost. The most effective and economical method for identifying potentially resonant conditions in blades utilizes a combination of modal test results and finite element analysis (FEA) to accurately predict the dynamic response characteristics of the structure under operating conditions. This combination includes information about natural frequencies and mode shapes.

REFERENCES

[1] Dimarogonas A.: Vibration for Engineers, Prentice Hall, New Jersey 07458, Second edition, 1996.

[2] Ewins D. J.: Modal Testing: Theory and Practice, Research Studies Press Ltd., John Wiley & Sons, 1986.

[3] Inman D. J.: Engiheering Vibration, Prentice Hall, New Jensey, 1994.

[4] Kaewunruen, S.; Remennikov, A.: Applications of experimental modal testing for estimating dynamic properties of structural components, Australian Structural Engineering Conference 2005 (ASEC 2005), Newcastle, Australia, 11-14 September, 2005 [CD ROM]. Copyright Institution of Engineers Australia. This paper is posted at Research Online: http://ro.uow.edu.au/engpapers/283.

[5] Rosca I. C.: Vibratii mecanice, Editura INFOMARKET, 2002.

[6] *** : PULSE – Getting Started, An Introduction to PULSE, Brüel & Kjær, September 2003.