The International Journal of Engineering and Science (IJES)
|| Volume || 6 || Issue || 9 || Pages || PP 80-86 || 2017 ||
ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

Experimental On-Line Damage Detection For Industrial Structural Components

B. Trentadue
DMMM - Polytechnic of Bari, Viale Japigia 182, 70126 BARI – Italy
Email: btrentadue@poliba.it

ABSTRACT: *Different numerical-experimental methods have recently been introduced in literature for the diagnosis of structural damages by using location-dependent changes in the modal parameters (natural frequencies, damping factors, mode shapes, etc.). The main task is the determination of presence, location and extent of the damage. This work is concerned with the possibility of introducing alongside a manufacturing process an on-line quality control for structural components prior to assembly using modal parameters. Basing on the natural differences among different components, the problem of error measurements, connected with available modal data, could become more noticeable than the health monitoring of an only particular system. Indeed, the modal data that should be used in diagnosing routines, belong to different systems which are obtained by different molding cycles carried out over different metal sheets. For this reason a deviation of the modal data, with respect to a mean value, should be assessed to appreciate the possibility to introduce an on-line quality control. Moreover, an experimental work benchmarking the deviation of such a modal data in the case we are dealing with is not available. In this work a certain number of structural components is experimentally tested in order to appreciate the deviation of the modal data. To this end, comparisons among mode shapes, natural frequencies and damping factors have been carefully examined and their relevant usability are discussed.*

Keywords: *damage, modal data, mode shapes.*

Date of Submission: 11 -09-2017 Date of acceptance: 23-09-2017

I. INTRODUCTION

Recent technologies realise chassis for cars by assembly of groups, sub-groups and structural elementary components. The assembly process is usually realised by welding joints. In such circumstances the structural integrity of the whole system depends on the integrity of single elementary components besides the quality of welding processes. Therefore, a quality control provided alongside the relevant assembly or manufacturing process, can be basically important for the integrity of the whole system. Figure 1 reports some examples of groups belonging to the technical area this work is dealing with.

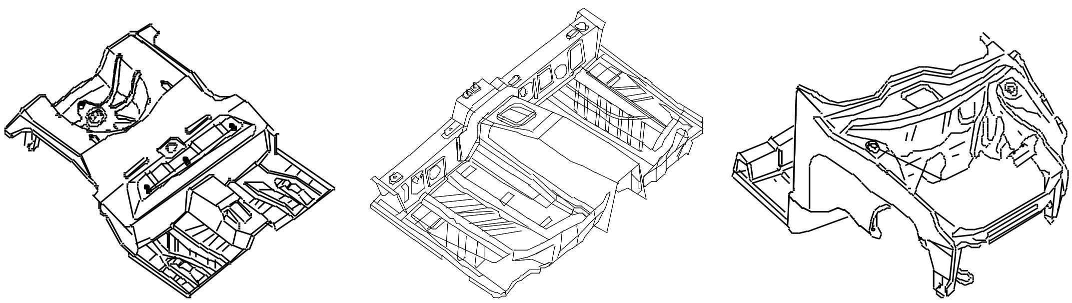

Fig.1: Typical Groups in automobile industries

In principle, non-destructive techniques (NDE) can, evidently, provide the chance to improve the requested security level to safeguard the whole structure. However, it remains to establish the particular NDE-technique (X-ray, ultrasonic, visual inspections etc.) that should assist the mentioned quality control. The technique should possibly account a trade off between costs and its own ability to test the integrity of the whole components, subgroups and groups.

Recently, different procedures, based on dependency of modal data on the structure state, have been proposed [1] assessing the health-state of several civil and mechanical systems. Basing on the characteristic of these techniques, it is believed they could provide the mentioned trade off. Indeed, several of the proposed methods make use of modal data, usually consisting in natural frequencies, damping ratios and mode shapes, related to the system to predict unexpected failures.

The modal data are dependent on the whole state of the system with a related different sensitivity with respect to the several local parts constituting the same system. Local changes on the monitored system can, then, be revealed by modal data shifts. Moreover, part of these data can, in principle, be evaluated by making use of an arbitrarily low number of sensors. These couple of characteristics make the sense of 'trade off' for the proposed application on quality control of semi-manufactured products.

However, some drawbacks related with this technique cannot be ignored for correctly diagnosing the state of the system. Namely, the main problems connected with the technique we are dealing with are essentially the number of available data and the error measurements that usually contaminate the same data. Indeed, it is not unusual that error measurements are present in such a way that a diagnosis can be transformed into an erroneous, rather than helpful conclusion.

These problems have been studied and discussed for laboratory tests and numerical simulation of several structures with good results [2,3]. But, this work deals with the variations of modal parameters for different systems which are obtained by different molding cycles carried out over different sheet metals. For this reason a deviation, with respect to a mean value, should be assessed to appreciate the possibility of introducing an on-line quality control. Her after, measurements of the usually extracted modal data are carried out on similar semi-manufactured, that are natural frequencies, damping ratio, mode shapes. For each class the measurements are discussed with respect to their possible usefulness and their stability alongside a quality control process.

II. APPROACH TO THE STUDY

The starting point of this analysis is from a recent search on certain structural parts of remarkable importance for the functionality of the vehicle being them elements of a structural subgroup to which the engine group and the organs of steering gear are connected. The figure 2 shows a FEM middle-small discreet representation [4], [10], of the connected real particulars. In the recent numerical work [4], the possibility to appraise meaningful deviations of the natural frequencies for diagnostic goals was underlined. In this work, the experimental results regarding a confirmation of the aforesaid numerical suggestions are introduced.

Such experimental confirmation was performed on eight specimens with similar geometric characteristic to the real components. The details taken in examination were gotten through cars conventional utensils simulating, in such way, a supply from bystanders to the buyer. Such elementary components were produced with geometry similar to that brought in figure 2 with the purpose to be able to align themselves with the numerical study already done [5]. The local bending or shape variations have not gotten further the components considered by the foreseen behaviour of the numerical study [4] because the wave lengths of the ways of interest were not such to be aroused great variations in comparison to the real components.

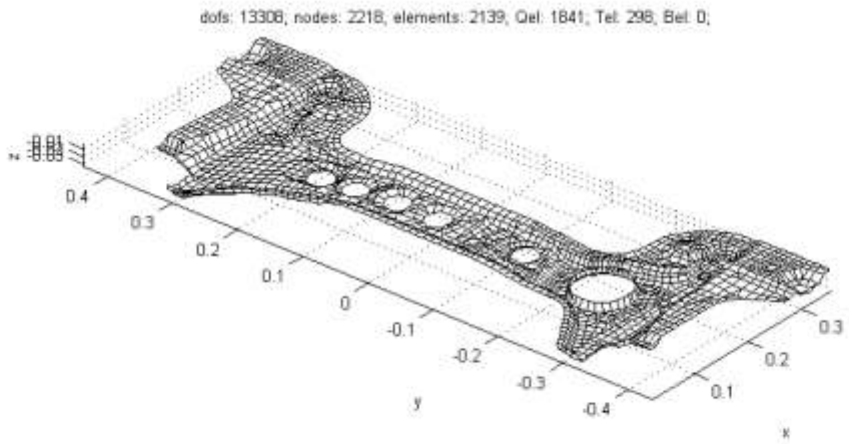

Fig.2: Analysed component

After labelling each specimen with a number from 1 to 8 natural frequencies and the associated proportional damping and mode shapes have been experimentally evaluated in the range 20-800 Hz. The specimens were suspended by rubber bands extremely flexible to simulate the boundary conditions such as completely free. They were beforehand marked with 26 points uniformly spaced on the surface to realise a grid of points (Fig.3) over which the relevant mode shapes were determined. This spacing of grid points was judge to be acceptable against possible spatial ‘aliasing’ problems with respect to the relevant mode shapes numerically estimated by FE procedures. Basing on the natural experimental difficulties all the measurements were realised with respect to the z-direction (Fig.3) neglecting the associated ‘in-plane’ parts.

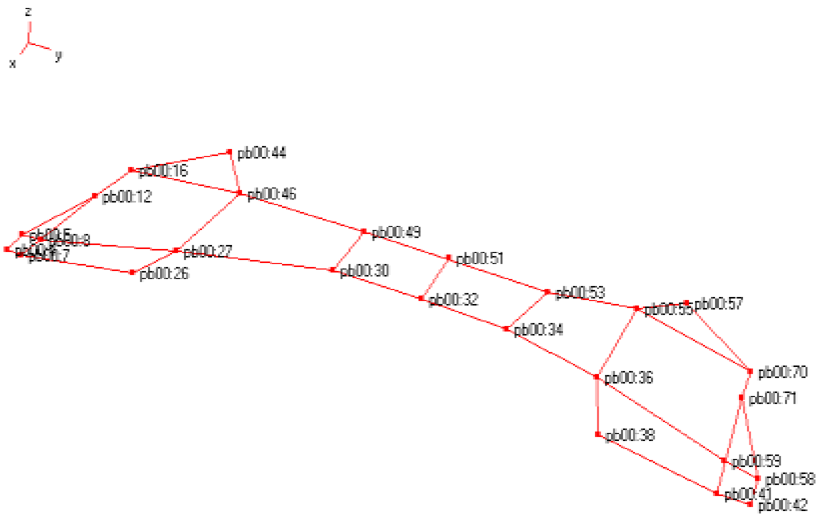

Fig.3: Experimental grid points for the specimens.

The FRF have been evaluated in the form of ‘inertance’ [5] by using an impulsive technique [5,6]. The impact hammer was moved around the 26 points having an accelerometer fixed, by wax, at the point 42. For each excited point were carried out different impacts to get an averaged FRF. In this respect four averages were retained an optimal choice to get the FRF with sufficient accuracy. All the measured FRF were then saved on disk and post-processed [7] to identify modal parameters.

III. NATURAL FREQUENCIES: MEASURE AND DISCUSSION

In table 1 there are the first 13 identified experimental frequencies. These 13 frequencies have been named in the order 1-13 (first column). However it is stressed that a few uncertainties were met during the identification for some modes, but, the first thirteen frequencies that were identified with good confidence are reported in table 1. The ‘xx’ staying for those frequencies that have not been distinguished with clearness in consequence of the measurement errors.

The second column lists the mean value for every frequency for the 8 analysed specimens. In the third column the standard deviation is also listed for all 8 specimens. It is immediate to verify that the values of corresponding frequencies for all the specimens are in extremely good agreement, showing a good repeatability.

Table 1. First thirteen identified natural frequencies (Hz)

			No specimen							
No freq.	Mean	Std Dev.	1	2	3	4	5	6	7	8
1	58.90	0.10	58.71	58.97	59.08	58.87	58.90	58.92	58.86	58.90
2	96.17	0.25	96.38	95.90	96.38	96.28	95.96	96.25	95.79	96.43
3	137.5	0.54	138.2	137.1	137.9	138.0	136.8	137.2	137.0	137.9
4	154.1	0.65	154.5	154.4	153.4	154.9	154.6	153.4	153.2	154.1
5	179.2	0.58	179.8	179.9	179.7	179.6	179.0	178.5	178.5	178.9
6	219.9	0.39	220.8	219.7	219.6	219.7	219.7	219.8	220.0	219.8
7	260.5	0.82	260.2	260.1	261.6	260.9	259.2	261.6	260.1	260.4
8	319.3	1.56	321.4	319.9	320.2	320.6	317.6	317.3	319.5	317.6
9	352.7	1.73	**xx**	353.0	352.6	354.8	351.3	350.0	352.2	354.7
10	472.0	2.03	474.3	474.1	471.1	471.3	468.4	**xx**	472.2	472.8
11	495.6	1.22	495.4	494.0	497.9	496.4	495.9	495.3	494.3	495.7

12	501.5	1.02	499.9	501.9	502.6	500.8	501.6	**xx**	502.8	501.2
13	531.0	1.60	529.2	533.5	533.2	530.5	529.8	529.7	531.4	530.9

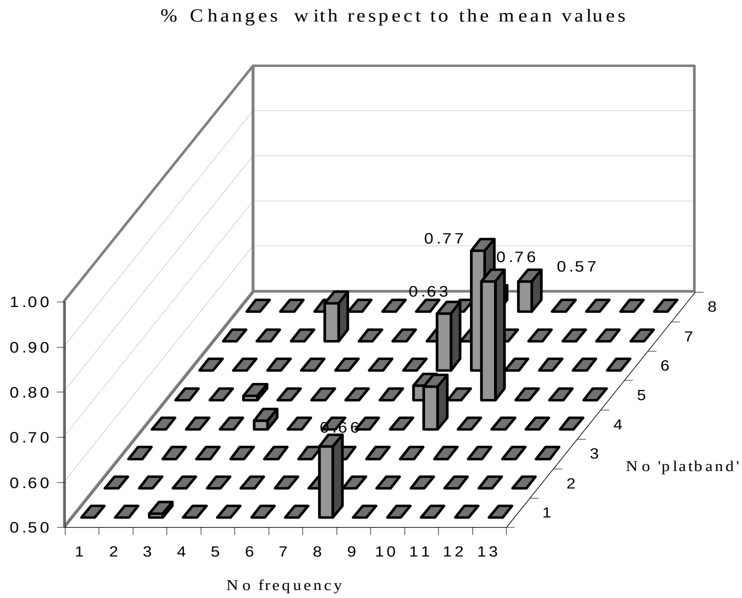

Fig.4: Percentage changes (|%|) of each frequency with respect to the mean value.

However, as elsewhere suggested [2,3], in different circumstances, it should be given importance to percentage changes of natural frequencies rather than to the relevant absolute changes. The main reason of this choice, is related to the fact that absolute changes naturally increase from lower to the higher frequencies, differently the percentage changes can then assist for weighting the absolute changes giving an approximately constant band. In such a way differences could better be appreciated. To this end figure 4 lists the absolute percentage changes (|%|) of each frequency with respect to the relevant mean value.

The base of the graph reported in figure 4 was settled to 0.5% to make evident the error band that was experimentally obtained on different components and for every frequencies. However, it is believed that such repeatability can be deteriorated with assembled groups or subgroups where joints can introduce additional uncertainties besides to spread the relevant modal data in a larger band.

The repeatability make a sense for these modal data to be used as possible candidates in quality control process. Finally, it is retained worthy of mention that these results (table 1) were obtained by approaching to the problem by a global point of view. Namely, the natural frequencies were obtained, once the full set of 26 FRFs, was available.

A full set of FRF means an expensive requirement and it is needed only whether the mode shapes are planned to be evaluated, as it was in this case. Conversely, the natural frequencies can be assessed in principle by making use of a couple of measuring points. This reduce the costs (times, hardware needed) and make the use of this modal data more attractive. To complete the discussion on using this modal data (natural frequencies) a few trials were carried out, herein not reported for brevity's sake, and no appreciable differences were obtained with respect to their stability as synthesised in both table 1 and figure 4.

IV. DAMPING: MEASURE AND DISCUSSION

During the identification process, natural frequencies can be evaluated together with the associated proportional damping for each mode. Experimentally it is quite well known that the stability of these parameters is worse than the stability usually found for the natural frequencies. In this respect other researchers reported large band errors [8]. Nevertheless, all the relevant damping ratios were estimated and tabled in the same as it was done for the natural frequencies. However, the deviations, absolute and percentage errors, were definitely poor with respect to the relevant mean values to extract any other conclusion than to simply avoid their using in diagnosing routines. Indeed, it was not unusual to achieve 60% of percentage error with respect to a mean value.

V. MODE SHAPES: MEASURE AND DISCUSSION

Finally, in order to complete the investigation on the possible modal data that could be used for diagnosing routines mode shapes of the specimens were also evaluated. It should, however, accounted that the first drawback for measuring mode shapes is the cost that could heavily influence the relevant cost of the final product.

For example, this work, concerns for each specimens 26x8=208 FRFs each one of which is the result of an average of four single measured FRFs for a total of 832 impulses carried out by hand from an human operator. Evidently, the measuring process can be improved making safe human being, by an opportune automated mechanical device. However, it remains the long time needed by the measuring process. Moreover, manipulating such mode shapes is not an immediate task. Indeed, many data means more complications, more sophisticated software and/or more professional operators. In figure 5 are shown the first 2 mode shapes associated with the first 2 frequencies for one specimen.

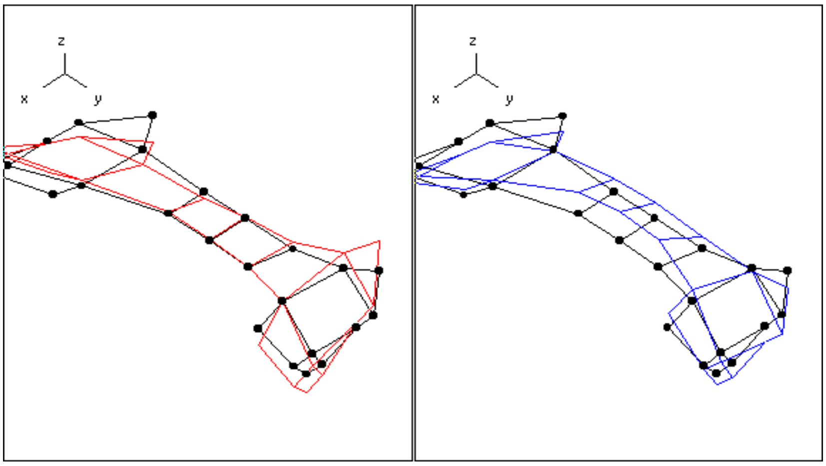

Fig.5: The first two mode shapes: torsional and bending modes

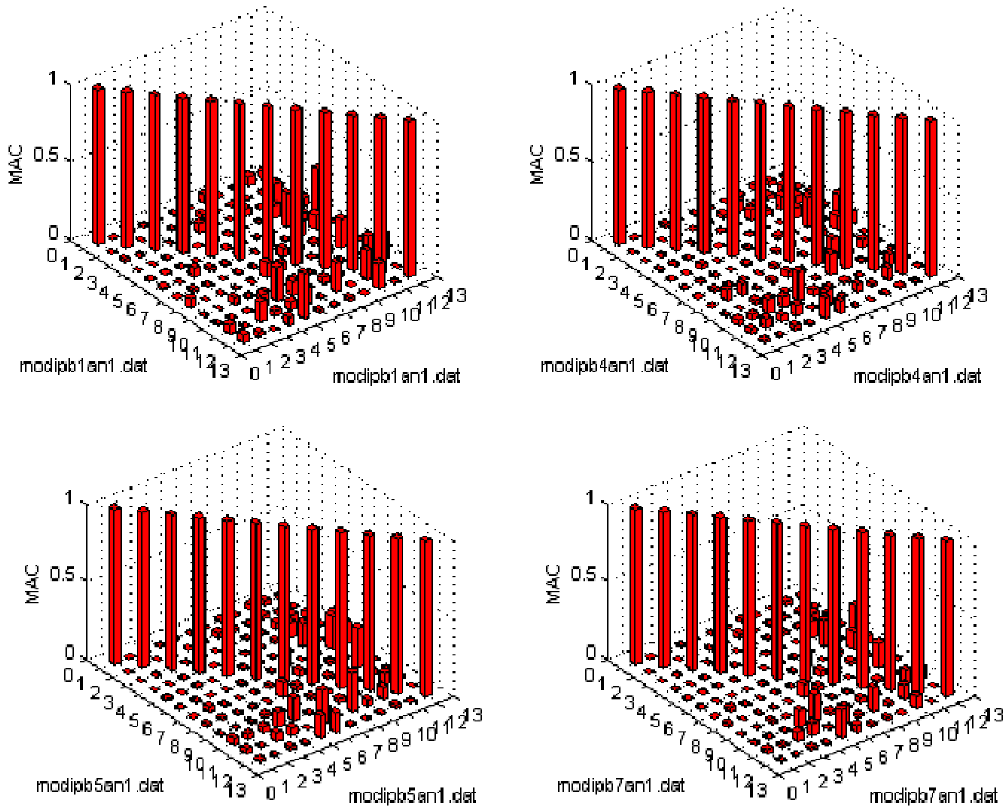

Fig.6: Comparing first 12 mode shapes by MAC [9,5,6] fixing each specimen 1, 4, 5, 7.

Figure 6 reports the relevant graphs displaying the MAC matrix [9,5,6] evaluated with respect to four different specimens. All these comparisons concern an experimental analysis (say 1) for the mode shapes concerned with J[th] specimen (modipb-J-an-1.dat). This validation tool constitutes a validating parameter for evaluating the quality of the estimated modal vectors. Other tools can be found in reference [6].

As well known, each MAC value give a correlation measure of the relevant couple of compared vectors, giving 1 for same modes and a value close to 0 for different modes. If, however, figure 6 estimates fairly good confidence, the quality of measured modal vectors, figure 7 compares each set of mode shapes obtained for the specimens 1,4,5,7 with relevant ones of specimen number 2.

These figures make evident that information concerned with similarity of different specimens is present but it was not immediately detectable mainly for the number of data to deal with.
Moreover, different modal vectors for different specimens showed a low correlation spite, by careful view examinations, appreciable differences were not immediately clear.

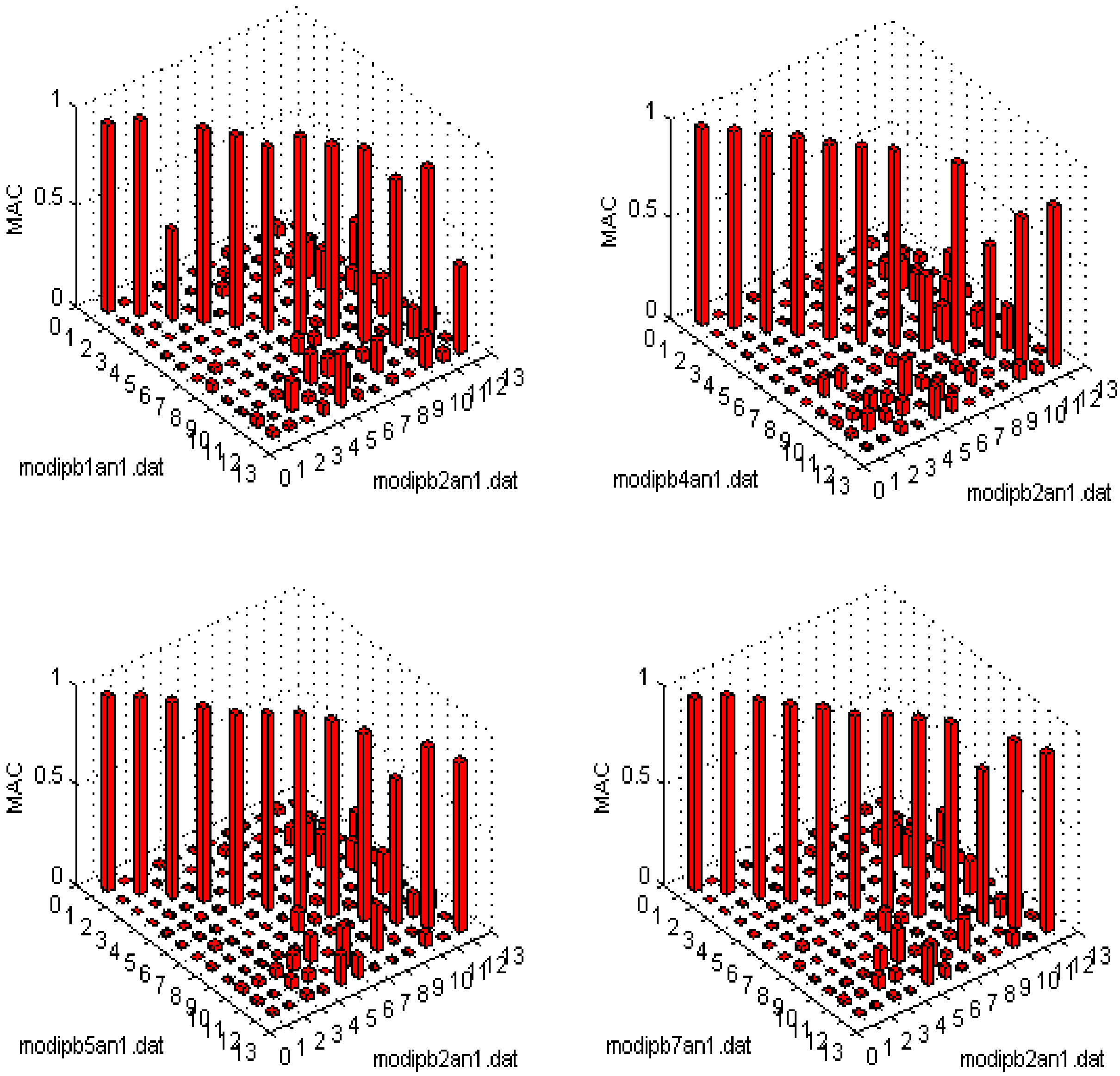

Fig.7: Comparing first 12 mode shapes by MAC [9,5,6] of specimens 2 with respect to specimens 1, 4, 5, 7.

VI. CONCLUSIONS

In this work has been realised an experimental study on the possibility of realising diagnosis of structural damages for structural components. This study has considered the location-dependence in the modal parameters from structural changes as possible tools to detect similar or dissimilar components. An enough high number of natural frequencies has been measured with a good repeatability. In this respect an absolute percentage error of approximately 0.5% has been detected making confident on using natural frequencies as possible candidates for the pursued objective. Indeed, the detected relative band error is fairly contained with respect to damages occurring in structural parts [4]. However, spite such a relative deviation from a mean value has been detected it is not believed it could be generalised when more complex systems are accounted and, therefore, an initial test, assessing the relevant deviation, could become a standard pass for the proposed quality control procedure. In concluding the stability obtained in case of a simple procedure dealing with natural frequencies only is encouraging for practical application. As for as the experimental stability is concerned, the results obtained on the natural frequencies cannot be extended to the damping ratios. The mode shapes showed a particular sensitivity, not immediately clear, amongst all the specimens analysed besides the complexity concerned in their using.

REFERENCES

[1] Doebling S.W., Farrar C.R., Prime M.B., Shevitz D.W., "Damage Identification and health monitoring of structural and mechanical systems from changes in their vibration characteristics: a literature review", *Los Alamos National laboratory report* LA-13070-MS.

[2] Contursi T., Mangialardi L.M**.,** Messina A**.,** "Detection of structural faults by modal data, lower bounds and shadow sites", *Journal of Sound and Vibration*, 1998, Vol. 210(2), pp. 267-278.

[3] Messina A., Williams E.J., Contursi T., "Structural damage detection by a sensitivity and statistical-based method", *Journal of Sound and Vibration*, 1998, Vol. 216(5), pp. 791-808.

[4] Contursi T., Mangialardi L.M., Messina A., Masciocco G., Montuori G., "Applicazioni industriali nella rilevazione di danneggiamenti strutturali mediante misure di parametri modali," *XIV AIMETA (in Italian)*, 1999, Vol.II, Como, ITALY.

[5] Ewins, D.J., "Modal testing: theory and practice", John Wiley & Sons Inc., New York

[6] Heylen W., Lammens S., Sas P., "Modal analysis theory and testing", Katholieke Universiteit Leuven, Dep.Mech. Eng., 1998, Division of Production Engineering, Machine Design & Automation.

[7] LMS CADA-PC Modal Rev.2.0, User Manual, LMS International 1998, Interlèuvenlaah 68,B-3001 Lèuven.

[8] Doebling S.W., Farrar C.R., Cornwell P., "A statistical comparison of impact and ambient testing results from the Alamosa canyon bridge", Proc. *15th IMAC*, 1997, Vol. I, pp. 264-270, Orlando-Florida, USA.

[9] Allemang, R.J., Brown, D.L., "A correlation coefficient for modal vector analysis", Proc. *1st IMAC*, 1982, Orlando, Florida, USA.

[10] B. Trentadue, A. Messina, N.I. Giannoccaro: "Detecting damage through the processing of dynamic shapes measured by a psd-triangular laser sensor Reference" International Journal of Solids and Structures, Volume 44, January 2007.

B. Trentadue. "Experimental On-Line Damage Detection For Industrial Structural Components." The International Journal of Engineering and Science (IJES), vol. 6, no. 9, 2017, pp. 80-86.