EXPERIENCING MODAL DATA ON QUALITY CONTROLS FOR STRUCTURAL COMPONENTS IN THE AUTOMOBILE INDUSTRY

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ABSTRACT

Different numerical-experimental methods have recently been introduced in literature for the diagnosis of structural damages by using location-dependent changes in 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, along with a manufacturing process, an on-line quality control for structural components prior to assembly using modal parameters. Based on the natural variations of different components, the problem of error measurements in connection with available modal data could become more noticeable than the health monitoring of a particular system. Indeed, the modal data that should be used in diagnosing routines belong to different systems that are obtained by diverse molding cycles carried out over various metal sheets. For this reason a deviation of the modal data, with respect to a mean value, should be assessed to appreciate the possibility of introducing an on-line quality control. Moreover, experimental work benchmarking the deviation of such modal data in the case we are dealing with is not available. In this work a certain number of structural components are experimentally tested in order to appreciate the deviation of the modal data. With this in mind, comparisons among mode shapes, natural frequencies and damping factors have been carefully examined and their relevant usability is discussed.

1.INTRODUCTION

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

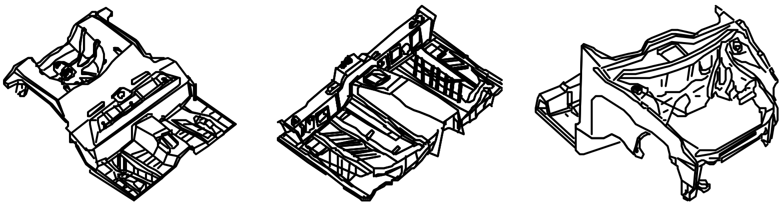

Fig.1 Typical Groups in automobile industries

In principle, non-destructive techniques (NDE) provide the opportunity to improve the requested security level in order to safeguard the whole structure. However, the particular NDE-technique (X-ray, ultrasonic, visual inspections etc.) that should assist the mentioned quality control has to be established. If possible, the technique should account for 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 the dependency of modal data in the structure state, have been proposed [1] assessing the health-state of several civil and mechanical systems. Based on the characteristic of these techniques, it is believed they could provide the above-mentioned trade off. Indeed, several of the proposed methods make use of modal data, usually consisting of 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 different related sensitivity with respect to the several local parts constituting the same system. Local changes in the monitored system can, therefore, 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 characteristic gives the sense of 'trade off' for the proposed application in quality control of semi-manufactured products.

However, some drawbacks related to this technique cannot be ignored in order to correctly diagnose 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 various systems that 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. Later, measurements of the typically extracted modal data are carried out on similar semi-manufactured products, that are natural frequencies, damping ratio, and mode shapes. The measurements are discussed for each class with respect to their possible use and stability alongside a quality control process.

2.PRESENTATION OF THE PROBLEM

The starting point of this analysis is from a recent search on certain structural parts of remarkable importance for the functionality of a vehicle being the elements of a structural subgroup to which the engine group and the steering gear organs are connected. Figure 2 shows a FEM mid-small discreet representation [4] of a connected real particular. 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 having geometric characteristic similar to the real components. In order to simulate a real supply, the examined components were obtained by conventional machine tools. Such elementary components were produced with a geometry similar to that brought in figure 2 with the purpose of going along with the numerical study already done [5].

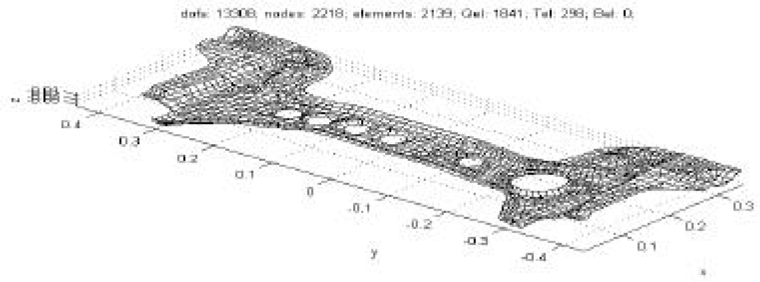

Fig.2 Specimen [4] (dim: m).

After labelling each specimen with a number from 1 to 8, natural frequencies and the associated proportional damping and mode shapes were experimentally evaluated in the range 20-800 Hz.

The specimens were suspended by extremely flexible rubber bands in order to simulate completely free boundary conditions. They were marked beforehand with 26 equally spaced points on the surface to create a grid of points (Fig.3) over which the relevant mode shapes were determined. This spacing of grid points was judged acceptable against possible spatial 'aliasing' problems with respect to the relevant mode shapes. Based on the natural experimental difficulties all the measurements were realised with respect to the z-direction (Fig.3).

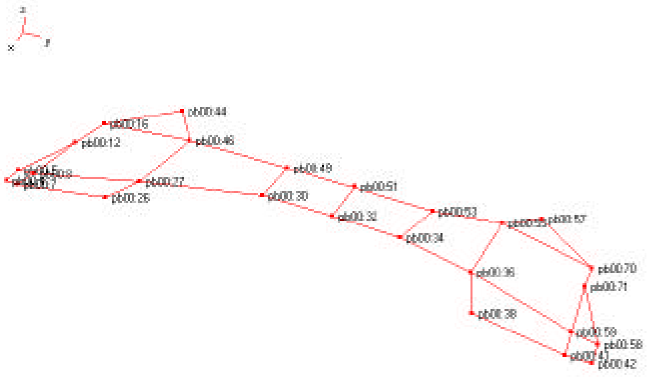

Fig.3 Experimental grid points for the specimens.

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

3. NATURAL FREQUENCIES: MEASURE AND DISCUSSION

Though some uncertainties were met during the identification process, table 1 contains the first 13 confidently identified experimental frequencies. The ‘xx’ stands for those frequencies that were not clearly distinguished in consequence of the measurement errors. The second column lists the mean value for each frequency for the 8 analysed specimens. In the third column, the standard deviation is listed for all 8 specimens. It is immediately possible 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

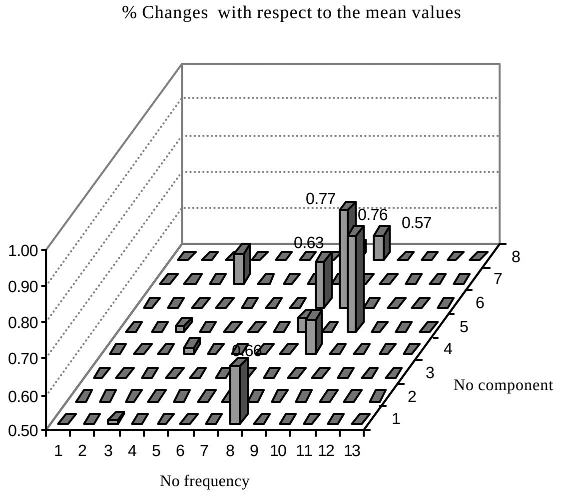

Fig.4 Percentage changes (|%|) of each frequency with respect to the mean value.

However, as previously suggested [2,3], in different circumstances, importance should be given to percentage changes of natural frequencies rather than to relevant absolute changes. The main reason for this choice is related to the fact that absolute changes naturally increase from low to the high frequencies [2]; dissimilarly, 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 show the error band that was experimentally obtained on different components and for each frequencies. However, it is believed that such repeatability can be deteriorated with assembled groups or subgroups where joints can introduce additional uncertainties other than spreading the relevant modal data to a larger band.

The repeatability makes sense for these modal data to be used as possible candidates in quality control processes.

Finally, it is worthy to mention that these results (table 1) were obtained by approaching the problem with 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 is an expensive requirement and is needed only when it is planned to evaluate the mode shapes, 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 reduces the costs (time, hardware needed) and makes the use of this modal data more attractive. To this end a few trials were carried out, herein not reported for the sake of brevity, and no appreciable differences were obtained with respect to their stability as synthesised in both table 1 and figure 4.

4. 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 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 was done for natural frequencies. However, the deviations, absolute and percentage errors were definitely poor with respect to the relevant mean values to extract useful and immediate conclusions for their using in diagnosing routines. Indeed, it was not unusual to achieve a 60% error with respect to a mean value.

5.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, be 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 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 by a human operator. Evidently, the measuring process can be improved making it safe for human beings, by an opportune automated mechanical device. However, a longer time is still needed for 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 the first 2 mode shapes are shown that are associated with the first 2 frequencies for one specimen.

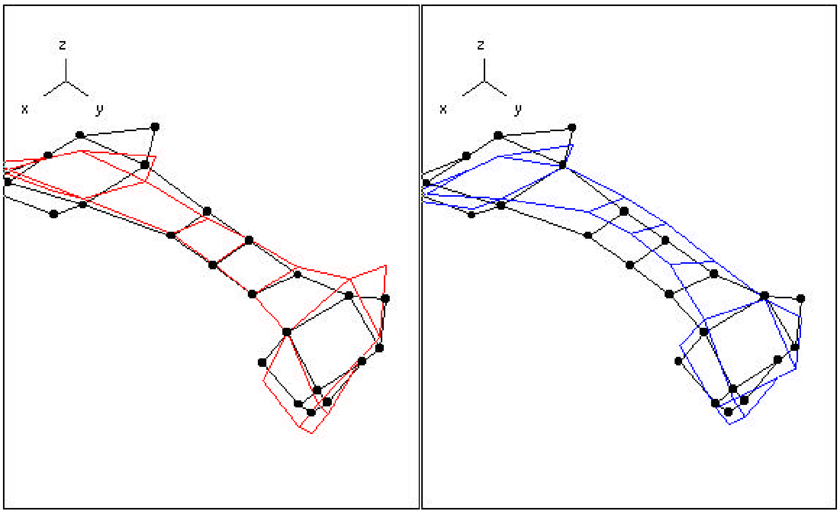

Fig.5 The first two mode shapes: torsional and bending modes

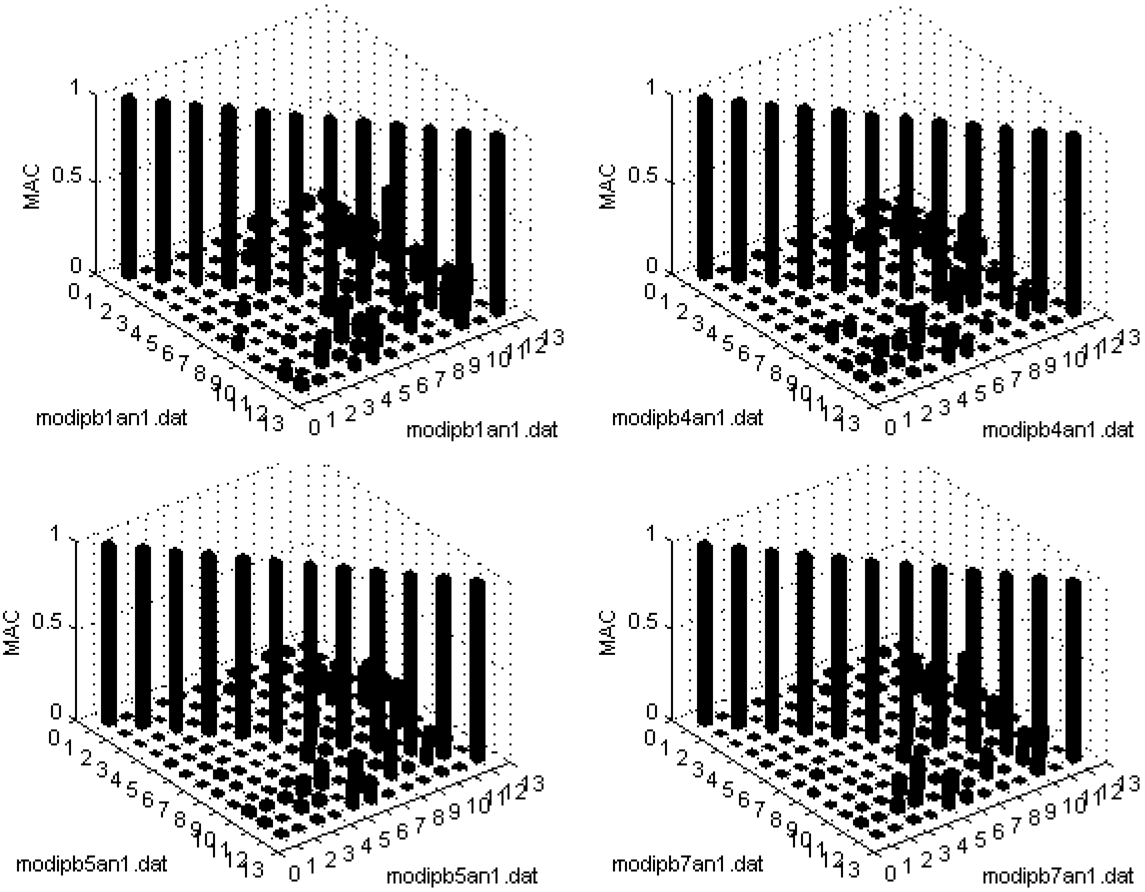

Fig.6 Comparing first 12 mode shapes by MAC [9,5,6] fixing each specimen 1, 4, 5, and 7.

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

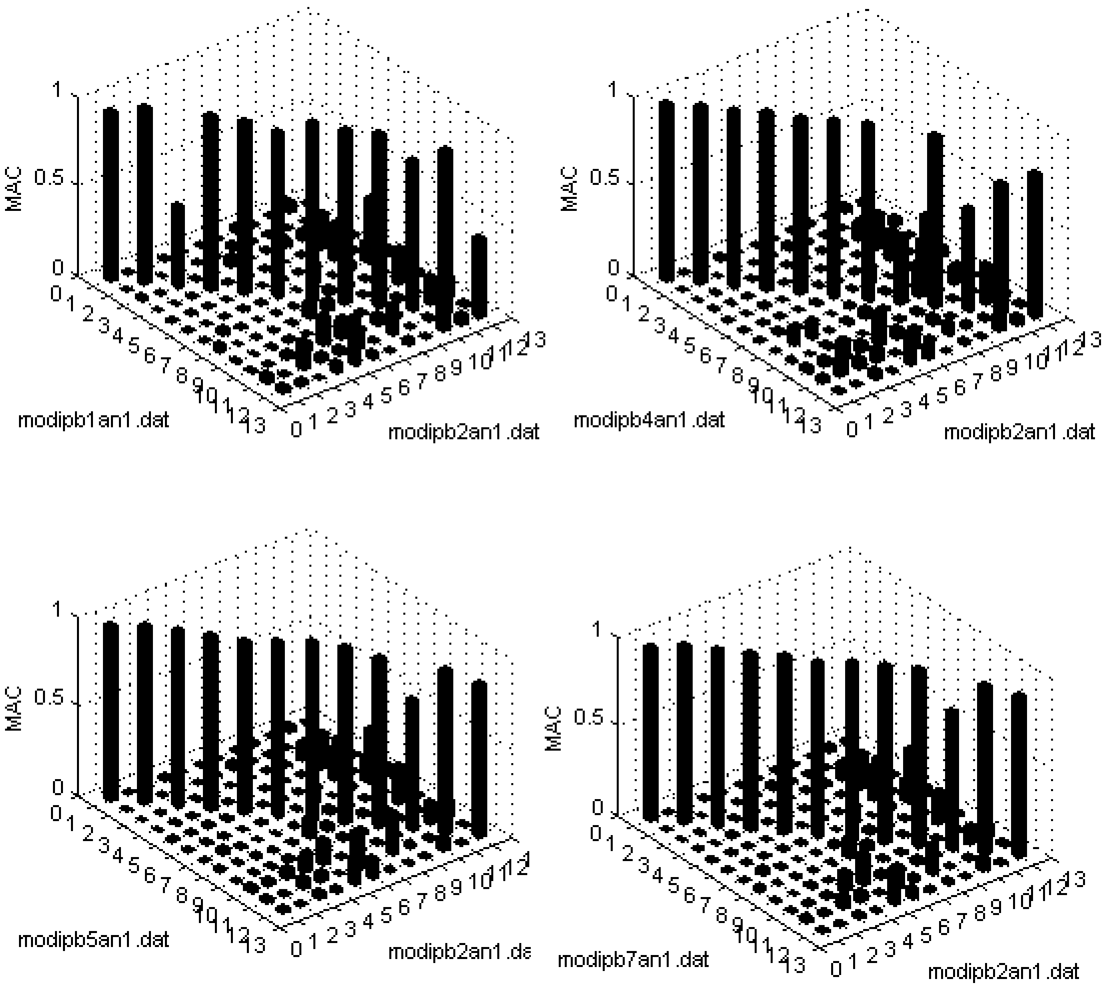

Fig.7 Comparing first 12 mode shapes by MAC [9,5,6] of specimens 2 with respect to specimens 1, 4, 5, and 7.

6.CONCLUSIONS

In this work an experimental study on the possibility of realising the diagnosis of structural damages for structural components was accomplished. This study considered the location-dependence in the modal parameters for structural changes as possible tools to detect similar or dissimilar components. A high number of natural frequencies were measured with good repeatability. In this respect an absolute percentage error of approximately 0.5% was detected making it a possibility to use natural frequencies for the pursued objective. Indeed, the detected relative band error is fairly contained with respect to damages occurring in structural parts [4]. However, in spite of detecting such a relative deviation from a mean value, generalising is not believed possible when more complex systems are accounted for. Therefore, an initial test, assessing the relevant deviation, could become a standard pass for the proposed quality control procedure. In conclusion, the stability obtained in the case of a simple procedure dealing with natural frequencies is encouraging for practical application. As far as the experimental stability is concerned, the results obtained in 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 other than the complexity concerned in their using.

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