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Methodology for experimental analysis of pipeline system vibration

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Abstract

There are presented two methods used for an investigation of modal parameters, concretely natural frequencies and modal shapes of a significantly simplified model of compressor yard pipeline system in this article. The first one is an experimental method and uses experimental modal analysis for that purpose with using of system Pulse6. The second method is finite element method and was performed in software Solid Works. The pipeline was built in on one side and elastically supported on the other side. The modal parameters of a pipeline system were evaluated for two cases. First one where springs of pipeline support were not preloaded and second one where preload was applied.

Keywords: modal analysis, pipeline system, PULSE6

Nomenclature	
FFT	fast Fourier transformation
TEDS	transducer electronic data sheet
CPB	constant percentage bandwidth

1. Introduction

This paper is concentrating on the utilizing of Pulse6 system of Brüel&Kjaer company by investigation of pipeline system vibrations. This presents a methodology which can be applied on real pipeline systems. The aim of our measurement was to determine modal frequencies and modal shapes of pipeline with respect to possibility of its support springs preload. The verification of these modal shapes was performed by using of finite element method in program SolidWorks.

Modal analysis

When we consider that every one system even every element has its natural (resonant or modal) frequency, in other words the property to oscillate with big amplitudes by small loading forces, it is inevitable to know about this dangerous frequencies. Modal analysis is good method for this purpose.

Modal analysis is not concentrating only for investigation of modal frequencies, but also looking for the modal shapes of vibrations and damping of the system. These three parameters we can label under the term modal parameters of the system. There is particular modal shape for each modal frequency. It is the shape which the system acquires when the loading force with particular natural frequency is applied. For objects with symmetric shapes the modal shapes are mostly symmetric too.

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Modal parameters are influenced by mass, stiffness and damping of the system and also by boundary conditions such that supporting of the particular system.

In the general we can divide modal analysis to experimental and operational. The experimental modal analysis is based on a transfer function which contains data about all system parameters. It means that for parameters calculation of a system is necessary to know input and output values. As an input values serves the actuator data, which can be electro-dynamic shakers (harmonics excitation), or modal hammers (transient excitation). The data acquired from the vibration sensors (accelerometers, vibrometers, etc.) are output values. The transfer function is then the ratio of output values to input ones. On the other hand the operational modal analysis is based only on the measurement of the system output, whereby loading forces are created by particular device operation. Operational modal analysis is mostly used in praxis where the investigated objects are situated in real conditions and in real supports.

2. Pulse 6

The system Pulse6 of Brüel&Kjaer company is a measuring device which is used for sound and vibration measurement. It presents a connection of the computer with particular software with a measuring module (fig.1). This software works under the operational system Windows and enables saving and analysis of measured data. Our used measuring device Pulse6 type 3560C contains 6 input channels. There is possibility to join sensors with frequency range from 0Hz up to 25,6kHz to these channels. Input voltage is measured in eight ranges from 7,071mV to 22,36V in steps at 10dB. The computer communicates with measuring module through the LAN interface.

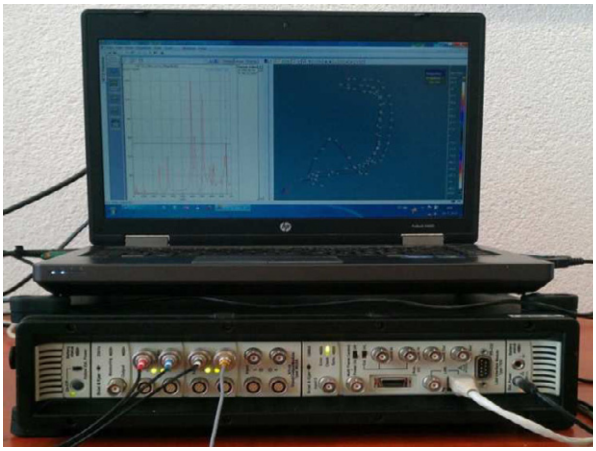

Fig. 1 Measuring device Pulse 6 of Brüel&Kjaer

Right setup of Pulse software is inevitable for correct results acquisition. This software enables:

- FFT analysis
- CPB analysis
- Level analysis
- Multianalysis
- Signal generation

By FFT analysis it is possible to setup item Lines. It is number of time records which are used for frequency spectra calculation. Its range is from 50 to 6400 lines. The bigger this number is, the better accuracy of the spectra is reached. The second item which can be setup is Span. It is size of a recorded frequency spectrum. It is possible to set it up at interval from 1,563Hz to 25,6kHz. The setting of Span and Lines determine frequency resolution marked as df, all time measurement T and sampling step dt. For our measurement we chose the value Lines as 1600 and the value Span as 1000Hz, consequent accuracy df reached the value of 625mHz which wholly suffice for this type of the measurement.

To simplify the work the system Pulse contains TEDS. It is ability to detect some kinds of sensors which are in advance predefined by producer. Other types of sensors it is necessary to define to this list of sensors and subsequently when it is needed one only choose the particular sensor from this list.

In our experiment are used Brüel&Kjaer's piezoelectric triaxial accelerometer of type 4506B and the modal hammer of type 8206 as an exciter (fig.2.). Modal hammer can be tipped with head of various stiffness e.g. rubber, plastic or metal.

Regarding to our experiment the plastic tip was chosen in terms of its convenient stiffness. It is capable to excite frequencies of a widest range and especially these one which are from central part of the frequency spectrum. Both devices were linked with measuring module Pulse and so they filled first four inputs (three occupied accelerometer and one modal hammer).

Fig. 2 Modal hammer with heads of various stiffness and triaxial accelerometer

3. Measurement

Modal analysis was realized in software MTC HAMMER of Brüel&Kjaer company in cooperation with the system Pulse6. The first step was to define used sensors, as it has already been mentioned above the piezoelectric accelerometer and modal hammer were used. Second step was a creation of investigated object geometry. This geometry can be created right in the software MTC HAMMER or can be imported from other programs e.g. Ansys. The geometry of our pipeline created in MTC HAMMER consists of 79 points lying along the pipeline in such way that these points properly described the real shape of the pipeline (fig.3.). These points were also places of pipeline excitation. The third step was an allocation of particular sensors to the measured points. In our experiment the accelerometer was applied for all the time of measurement to the one point, meanwhile the excitation was performed in remaining points. From theoretical aspect it does not matter whether the sensor of vibrations is fixed (it will measure the vibrations only in one point) and the place of excitation is changing or the place of excitation is for all the time same and the measuring places are changing. In practice is more convenient to use the first way. The fourth step was to set up required frequency range and set up the sufficient number of lines which are used for frequency spectra calculation. As it was mentioned earlier the value Lines was 1600 and Span 1000Hz. With respect to that the modal hammer hit can introduce into the experiment some errors or particular hit need not to be ideal it is necessary to average these exciting forces. For this reason there is an item Averages which was set up in our instance to average values from three hits. The next step was to set up the Double hit detector. It is nearly not possible with human senses to detect by using of modal hammer whether there is some double hit even triple hit what would probably occurred as unwanted noise. Therefore the system is equipped with double hit control function which sensitivity can be adjusted. The last step before the measurement was to set up an acceptable impact force of the modal hammer. Very weak and very strong hits are not included into the measurement when this function is set. In ideal case our measurement would be composed from the series of three hits on 78 points.

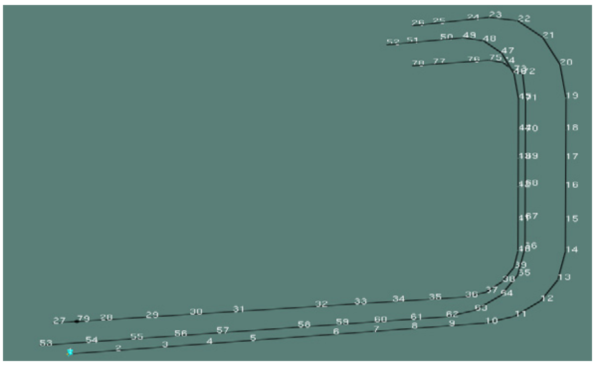

Fig. 3 The single model of pipeline created in MTC Hammer software.

As the model the part of compressor yard pipeline system was chosen. It is spatial system composed with three pipes joined with elbows with 90° angle (fig.4a). The aim of measurement was not to create true copy of the pipeline system but retain the main shapes and places of its support. The pipeline was fixed on one side and on the other side it was supported by springs with variable preload. The place of a fixation was realized by holders fixed to the stand (fig.4b). The material of the pipeline was predominantly zinc 99,995%, alloyed by copper and titanium.

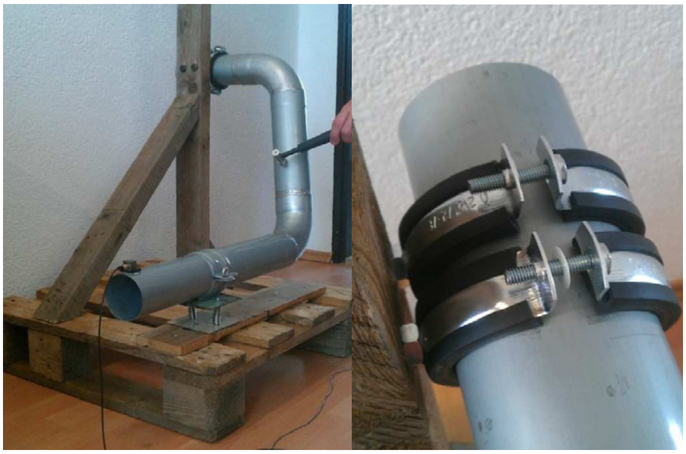

Fig. 4 The pipeline model a) the whole model b) place of fixation

4. Results of the measurement

The aim of the measurement was to find out natural frequencies and modal shapes of pipeline model for two cases. The first case when springs of elastic support were not preloaded and when they were. Measurement results comparison acquired by Pulse6 for the case when springs were not preload with the results acquired by software Solid Works are presented on next figures (fig.5 - fig.14).

Preload of pipeline support springs was created in one half of their length and the second half conserved its previous stiffness. Modal shapes did not differ for both investigated cases but differ in natural frequencies. From this reason we present only natural shapes of the first case, without preload.

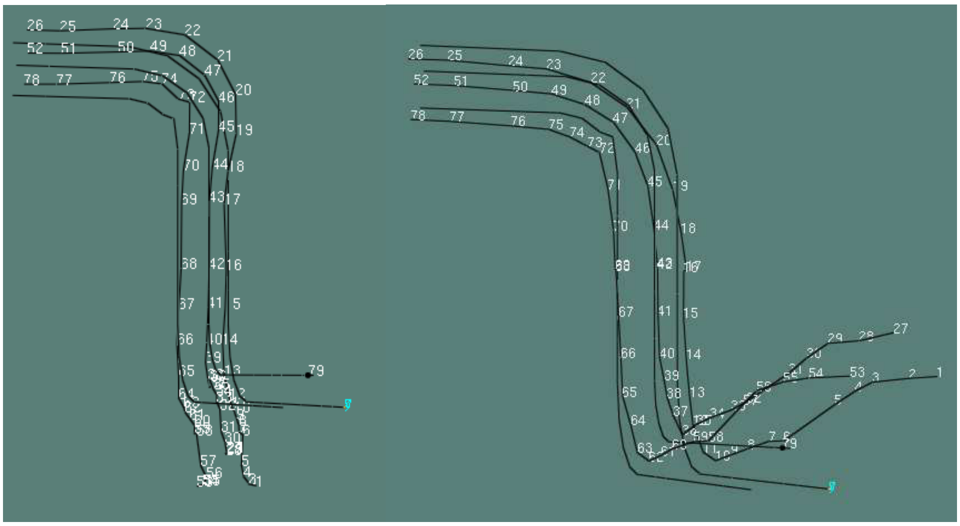

Fig. 5 The first modal shape in MTC Hammer

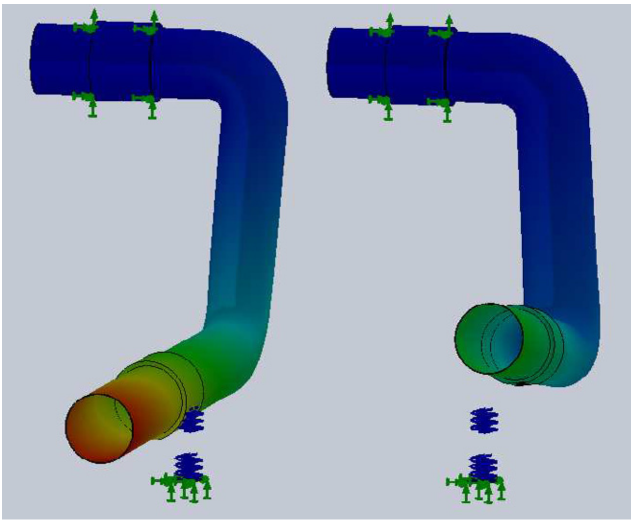

Fig. 6 The first modal shape in Solid Works

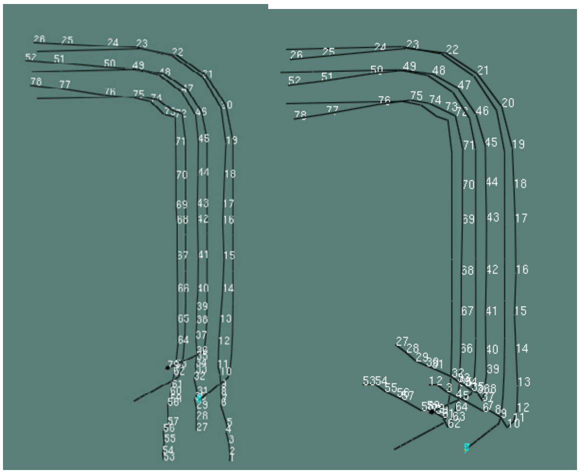

Fig. 7 The second modal shape in MTC Hammer

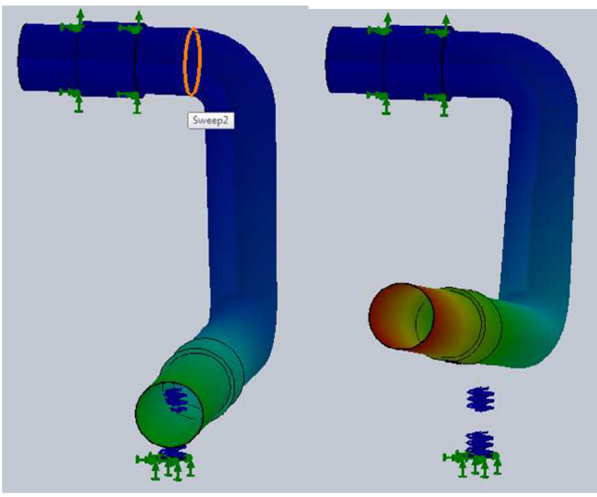

Fig. 8 The second modal shape in Solid Works

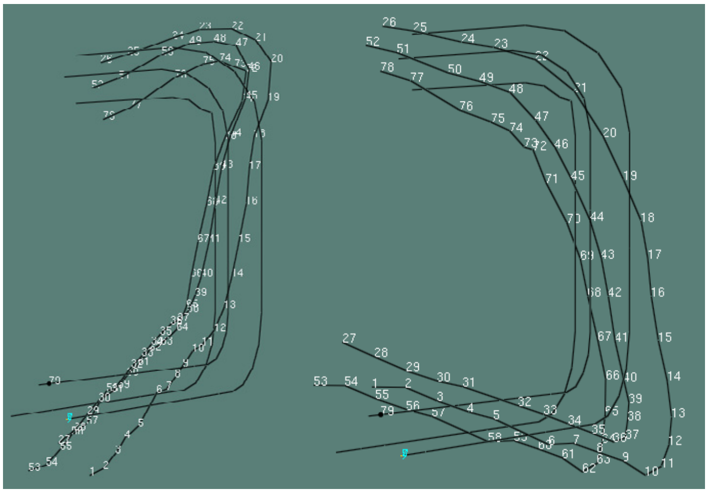

Fig. 9 The third modal shape in MTC Hammer

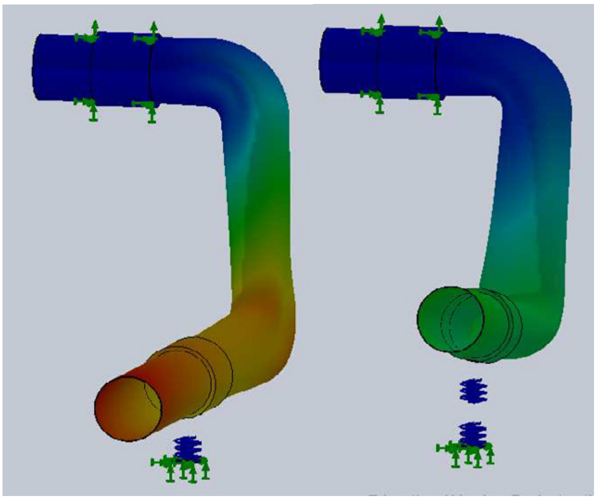

Fig. 10 The third modal shape in Solid Works

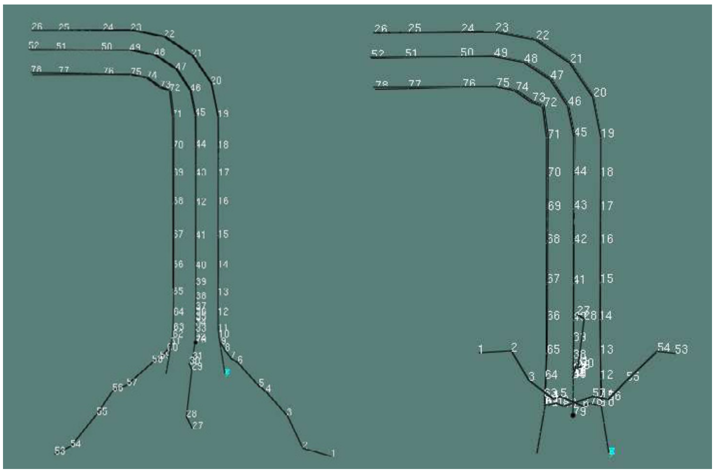

Fig. 11 The fourth modal shape in MTC Hammer

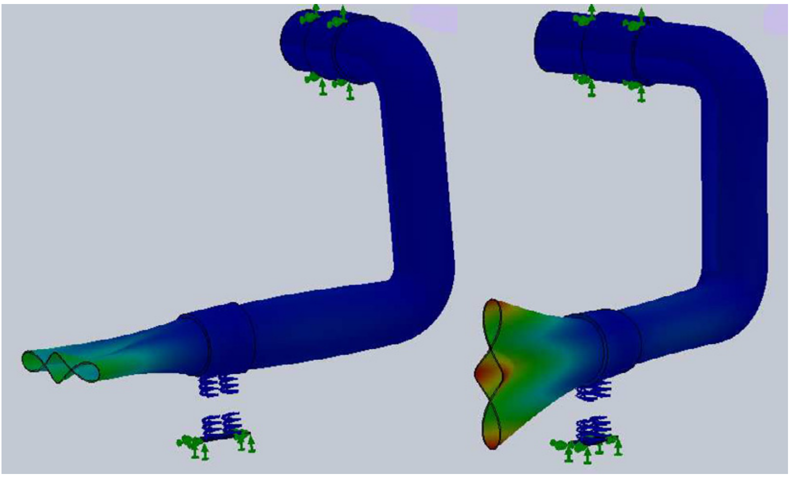

Fig. 12 The fourth modal shape in Solid Works

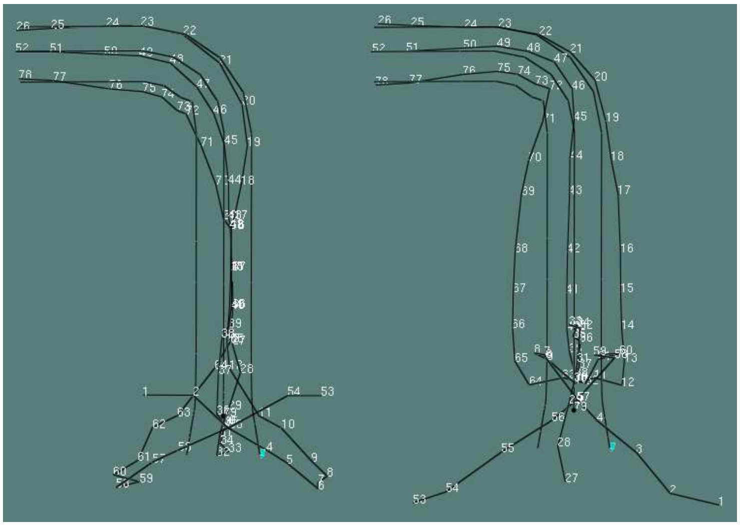

Fig. 13 The fifth modal shape in MTC Hammer

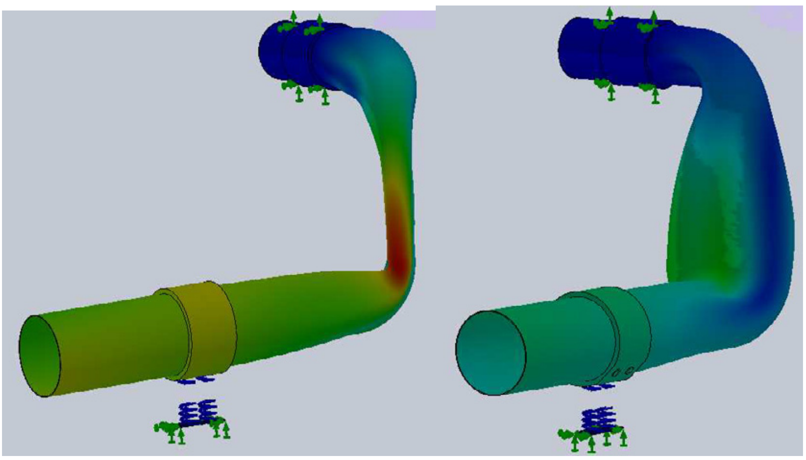

Fig. 14 The fifth modal shape in Solid Works

As we can see from the images there is from fourth modal shape also a deformation of pipeline cross-section and not only distortion of its shape.

Corresponding natural frequencies of the particular modal shapes are presented in a table 1.

Table 1. Natural frequencies of corresponding modal shapes

Natural frequency no.	*1.*	*2.*	*3.*	*4.*	*5.*
MTC Hammer	*20,5Hz*	*36Hz*	*82Hz*	*263Hz*	*350Hz*
MTC Hammer P	*25Hz*	*42Hz*	*85Hz*	*263Hz*	*352Hz*
Solid Works	*29,8Hz*	*35,5*	*86,3Hz*	*282Hz*	*374Hz*

Where MTC Hammer means the measurement of pipeline vibration by system Pulse when the springs were not preloaded and MTC Hammer P means the measurement of pipeline vibration by system Pulse when the springs were preloaded. The results acquired by software SolidWorks are for the case when springs were not preloaded.

5. Conclusion

From our results we can see that method of determination of natural frequencies and modal shapes with Pulse6 system is convenient but tedious. For replica creation of arbitrary shape-difficult object it is necessary to create sufficient number of measuring points what considerably extend measuring time because every point is necessary to excite several times. Also some locations are not possible to excite or measure due to insufficient needed space. First three modal shapes represents only rotations of particular pipeline parts and from fourth modal shape begin the deformation of cross-section. Due to small number of measured points in software MTC Hammer next modal shapes significantly differ from those acquired in SolidWorks. The results shows on a fact that springs stiffness was too high and so the preload did not have significant effect on the modal parameter change.

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