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STRUCTURAL DYNAMIC IDENTIFICATION ON THE EXAMPLE OF COMPRESSOR-FOUNDATION

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Summary: *To be able to influence the vibration of real structure it is necessary to identify its dynamic behaviour. Identification of modal parameters as frequency spectres, modes of vibrations etc. by measurement is very reliable method. By utilisation of powerful computers can be determined also all modal parameters by computation. If already dynamic parameters have been identified, and agreement of measured and computed results obtained, it is possible to study by calculations many modifications of the structure in order to find the best solution. The above cited method will be demonstrated on the example of compressor-foundation.*

1. Introduction

In order to influence the dynamic response of the structure it is necessary to identify its dynamic behaviour to be possible to design realistic FEM model. The very often used method in this case is the method of identification. These methods have been intensively developed in the last years, thanks to the comprehensive development of computer as well as measurement techniques. The modal parameters as natural frequencies, modes of vibrations and modal masses are usually determined by measurements. The FEM model is than adjusted by inverse methods according to identified parameters so, that the agreement between calculation and measurements will be obtained.

The assumption that the measurement of modal parameters can be carried out with high accuracy must be by utilization of this method satisfied. The measurements of natural frequencies have been so developed in last time that also very high accuracy has been available.

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The suitable methods have been developed also for inverse solution of technological systems with limited degrees of freedom. For complex civil engineering structures is still the measurement of natural frequencies and corresponding modes of vibration very problematic. Also the mathematical solution of inverse problem is very laborious.

But it is still possible, even in the case of large civil engineering systems, to compare measured and calculated dynamic parameters and by disagreement to repeat the calculation using improved calculation model. This step can bee repeated several times till good agreement will be obtained

But by utilization of powerful up to date information techniques enables also consulting offices to calculate big FEM models with thousands degrees of freedom and in this way to investigate many structural alternatives. Here presented method verified the calculation model by verification of amplitudes of forced vibration in significant nodes of the structure. By use of this verified FEM model structural alternatives have been investigated and the most suitable solution with forced amplitudes within the allowable limits has been found.

2. Brief Description of the Structure

The original foundation for the compressor Ingerssol Rand was built and the compressor was assembled about 30 years ago. The compressor Ingerssol Rand is the compressor of "boxer type ", it means there are three cylinders placed in horizontal direction, the first cylinder on one side and the second and third cylinders on the other side, working against each other (ref.Fig.1)

Fig. 1:Compressor Ingerssol Rand

Fig. 2: Steel frame supported by spring units

The compressor-foundation was built in the form of very heavy and rigid reinforced concrete block supporting the central part of the compressor. The cylinders have been supported by separated concrete supports. These supports as well as the central supporting block have been placed on the common foundation concrete plate about 100 cm thick. It is well known that the exciting forces, (in vertical, horizontal directions and torsion moment around vertical axe) by these types of compressors are extremely high, but despite that, the amplitudes of excited vibrations have been satisfactorily on the foundation. On the other hand the transfer of vibrations in the vicinity of the compressor has been too high. The latest has resulted in problems, particularly in the last time, because the new machines (as up to date compressors etc), sensitive to dynamic excitation from outside, have been installed. Beside that, on the central upper part of the compressor-foundation have occurred very deep cracks and amplitudes of forced vibration have increased. From above cited reasons, the reconstruction of the foundation has been carried out. The upper part of the

block foundation as well as the separate cylinder supports have been removed up to approximately 1 m above foundation plate.

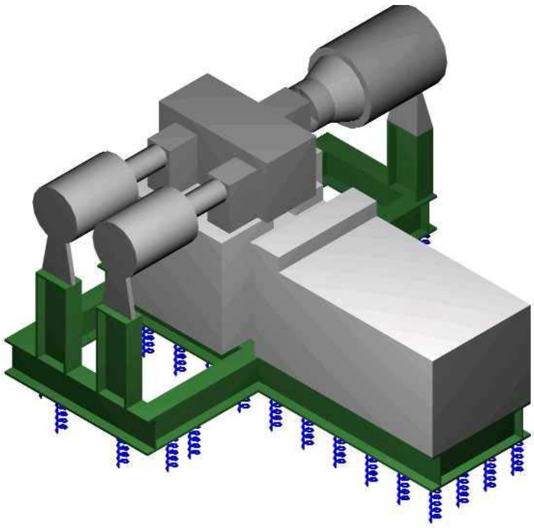

Fig. 3: Scheme of the foundation after reconstruction

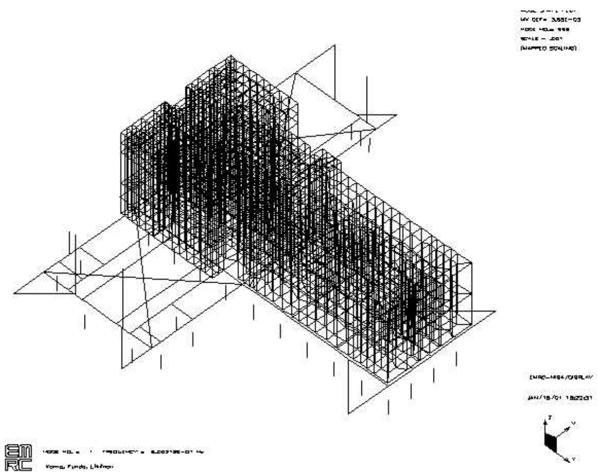

Fig. 4: FEM calculation model

The very rigid steel frame has been installed on the remaining lower part of the foundation. This steel frame is supported by the special spring units (delivered from the company GERB, Germany), with extremely low spring constants, both in vertical and horizontal directions, ref fig.2 and 3. The operational frequency of the compressor is only 7 Hz and the second harmonic frequency 14 Hz. From this reason the spring units with the spring constants 0.56 kN/mm in vertical and 0.08 kN/mm have been used in order to obtain maximal possible difference between the frequencies of first modes of the foundation and the operational frequency of the compressor. The new foundation upper concrete block was then placed on the steel frame. The compressor was connected to the foundation block in the same manner as before, the cylinders are supported directly by the steel frame. The steel frame has been used mainly with the respect to the limited space in this place.

It has been proved in the operation after the reconstruction, that the aim to decrease the transfer of vibration has been perfectly satisfied, but the amplitudes of forced vibrations of foundation and the compressor itself have gone beyond allowable limits. This problem has been analysed and by comparing of measurement against calculation it has been found, that exciting forces, given in the original compressor drawings have been incorrect. The new correct exciting forces have been determined. The movable parts of the compressor have been weighted and all exiting forces have been determined by the calculation of not balanced forces. The correct exciting forces have been almost twice as much as it has been given in the original drawing.

3. Measurement and Verification of model

The new correct exciting forces have been introduced in the FEM model and the new calculation has been performed. The calculation model has been verified by comparison of measured and calculated results verified according to the flow diagram presented in the (fig.5).

The verification have been completed very fast and good agreement of measured and calculated data has been obtained, (ref. fig.6, 7)

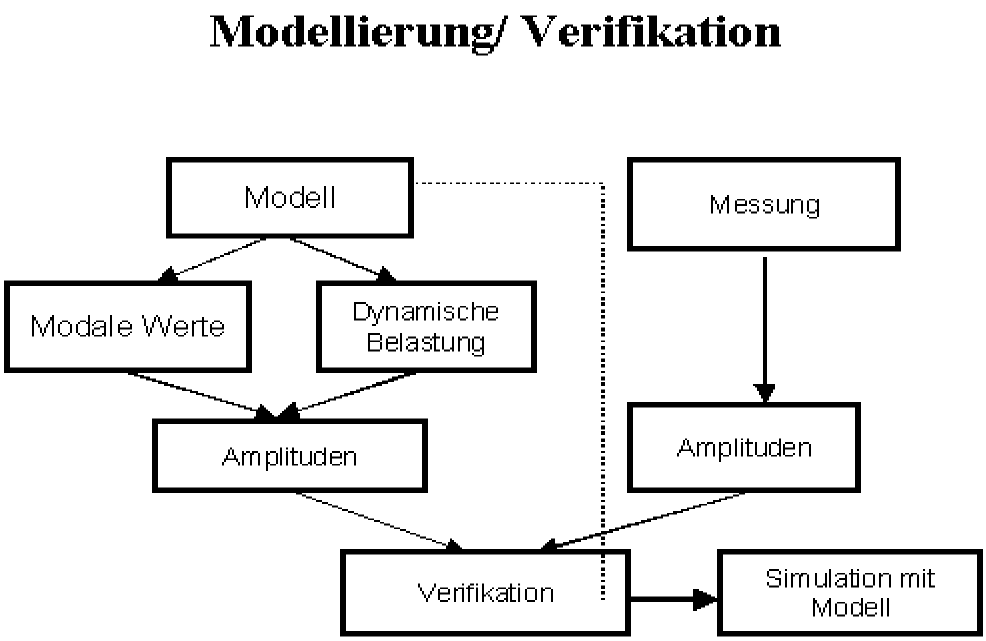

Fig. 5: Scheme of the Verification

The verification has been performed exactly according the flow-diagram shown in the fig 5. The modal parameters and amplitudes of forced vibrations have been determined using the original calculation model loaded with the new values of exciting forces. The results of this calculation have been compared with the measured data. Than the calculation model has been improved by disagreement of measured and calculated data and the calculation has been than repeated. This loop has been repeated several times, till the required agreement have been gained.

The described method can be also used for more complicated structures, on the condition, that the powerful computer as well as suitable software are available.

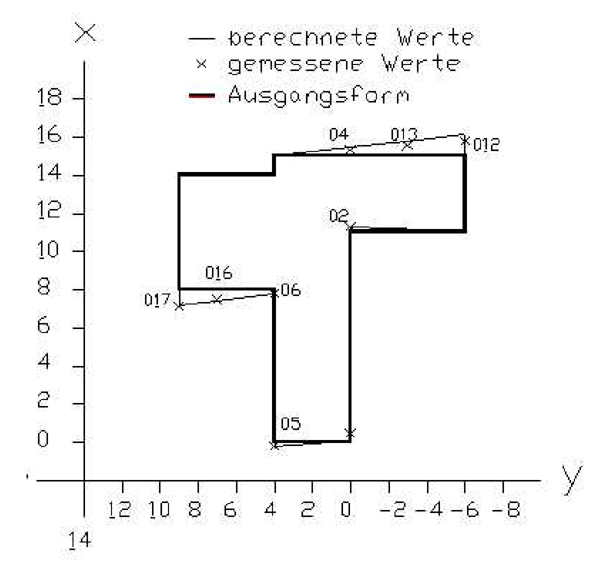

Fig. 6: Amplitudes in x-direction

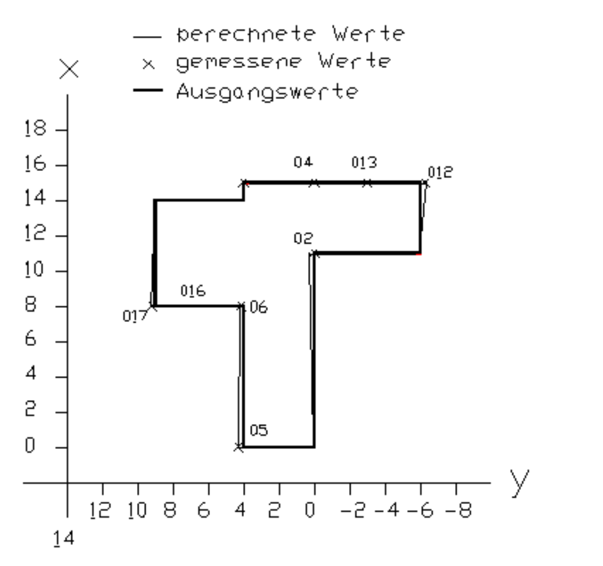

Fig. 7: Amplitudes in y-direction

4. Investigation of different Variants

After verification of calculation model and introducing the new correct exciting forces, it was possible to analyse different variants of structural improvements in a very reliable way.

The aim of this improvement was to find structural adaptation which will by most effective way result in reduction of forced vibrations amplitudes up to bellow allowable limits. It could be expected that the variants analysis will be performed very reliably because of FEM model and exciting forces verification.

The „in that time existing structure“ has been analysed in detail firstly. It has been found that the maximal contribution to the global amplitudes of forced vibration were by the new and much higher exciting forces coming from the dynamic deformation of the steel frame despite its relative high rigidity. The variants of improvement have been therefore mainly aimed to increase the rigidity of the steel frame in its plane.

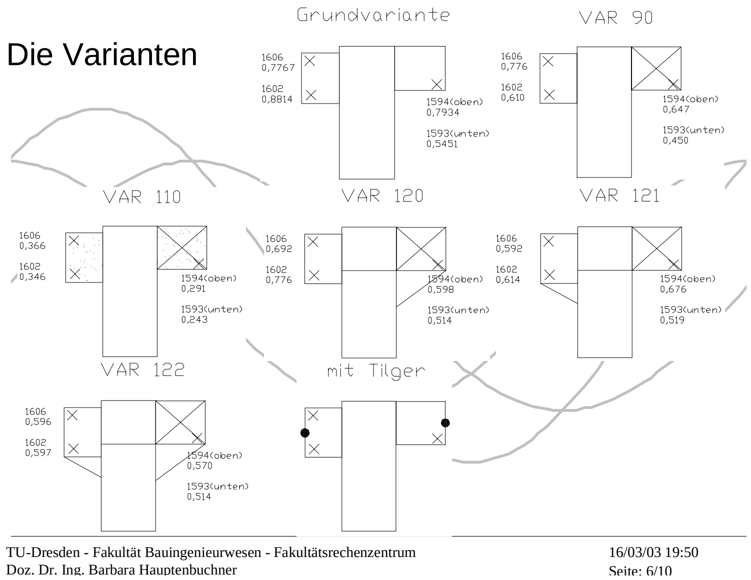

Fig.8: Variants of the adaptions

About 12 variants have been investigated by the calculations using correct exciting forces and verified calculation model. Some of these variants will be presented in this contribution now. Following variants will be presented, (ref.: Fig.8).

- Structure after reconstruction, without any adaption
- Variant 90 –steel frame is reiforced by new more rigid diagonals
- Variant 110 – the same as variant 90, the steel frame is on both sites filled with aditional dead load, (sand, or steel plates etc.)
- Variant 120 – as variant 90 with aditional diagonal outside on the right side
- Variant 121- as variant 120 but with aditional diagonal on the left side
- Variant 122 – with aditional diagonal outside on both sides
- Variant with Tuned Mass Dampers

For all variants the natural frequencies, corresponding modes of vibrations amplitudes of forced vibration, in important selected nodes and time history of vibration have been determined. Some of 2A amplitudes, (peak – peak) of forced vibration can be found in the fig. 8, together with the numbers of nodes. It should be noted, that the allowable 2A amplitudes are 800 µm in the plane of compressor anchoring to the foundation

Natural frequencies can be seen in the Fig 9 for the structure after reconstruction, without adaptation. It should be pointed out that the mode of vibration No.: 13 with the frequency 10.95 Hz contributes very much to the resulting amplitude. In the fig 11, referring to the variant 122 can be found that this frequency and corresponding mode of vibration have been

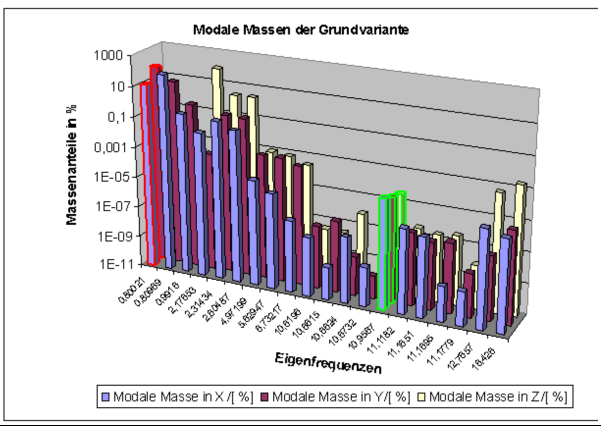

Fig.9. Naturals frequencies without adaptation

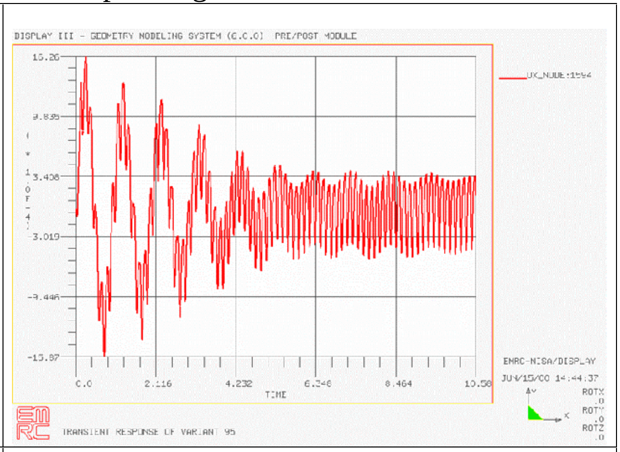

Fig.10: Amplitudes of node under cylinder

moved to frequency 25.22 Hz, more different from exciting frequency 7 Hz as it was before reinforcement of the steel frame. The latest has resulted in substantial reduction of forced amplitudes. The example of time history of the amplitudes at the node where the 1st cylinder is supported on steel structure can be seen in the Fig, 10 before and in the Fig.12 after adaptation according the variant 122.

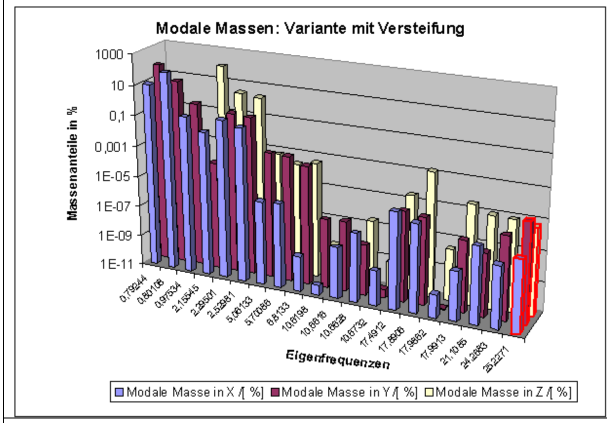

Fig. 11: Naturals frequencies Variant 122

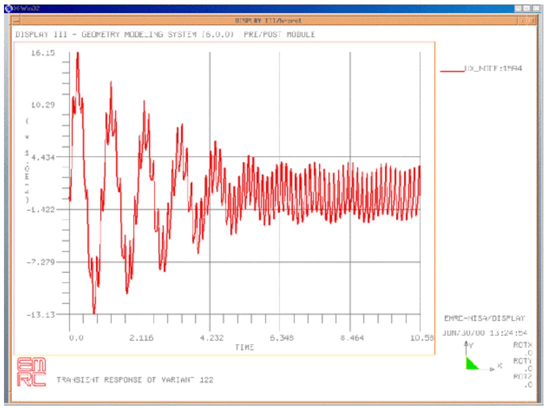

Fig. 12:Amplituds of nodes under first cylinder

5. Conclusions

All calculated variants have been analysed, particularly from point of view of amplitudes of forced vibration in reference points. It can be noted (ref. Fig.8) that after strengthening of cantilevers of the steel frame, using more strong diagonals and diagonals outside, (ref. Fig.8) Variants 90, 120, 121, 122, already satisfy the required limits of vibration. In order to obtain really very good dynamic behaviour of the structure as well as of the compressor itself, the variant 110 with the most effective reduction of vibrations has been realised. This variant is based on the combination of the steel frame strengthening with more rigid and additional diagonals with the increase of increase of the total weight by using additional dead load. This additional dead load in the form of steel plates has been placed inside the cantilevers of the steel frame. This solution has involved some increase in the total costs, because additional spring units have to be added under the foundation block with the respect to the increase of the weight.

The very good agreement between measured and calculated amplitudes have been found the whole period for about two years since the start in operation.

It can be concluded that the method of dynamic structural identification is very powerful method which can be always used for the analyses of existing structures or systems of machines-structures in the case when these systems or structures must be improved. The authors do believe, that this method can be also used for more complicated structures as it was demonstrated in this contribution.