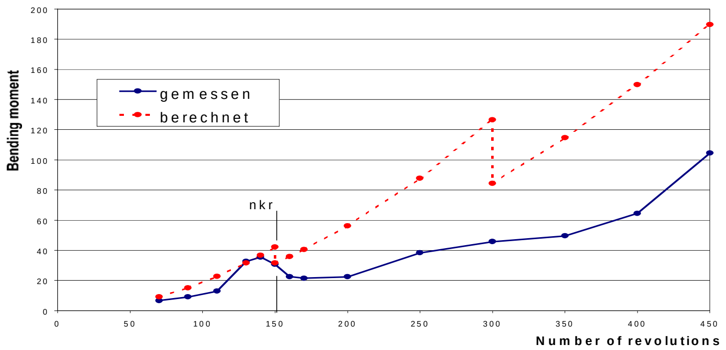
THE DYNAMICS OF ROTORS

Project manager: Dipl.-Ing. K. Butter Duration: 05/99-06/00

Initial situation

Agitators are used in many sectors of industry for stirring a wide range of media. Designing agitator shafts to meet the bending strain on the shafts and possible vibrations on both shafts and agitators as a whole is still a highly uncertain business which often results in over-sized agitators. The following is an example.



gemessen = measured
berechnet = calculated

At high rotational speeds, the actual bending moments measured are considerably lower than those that could be expected according to the works calculation standards used. As a result, agitator shafts made of high-alloy steel are often designed over-sized and too expensive in manufacture.

The calculation standards used are generally based on investigations conducted partially a couple of decades ago and present the different stirring elements and hydraulic excitation forces - causing dynamic bending moments - in the form of standardized radial force coefficients. Standardization at that point of time was based on the similarity laws of fluid mechanics as well as scale-up methods, considering the following parameters:

- the diameter of the stirring element,
- the rotational speed of the stirring element,
- the density of the medium to be stirred.

The damping effect created by the medium itself was considered to be insignificant.

The bending moments in the shaft caused by hydraulic forces were measured, and the relationship

$$F_R = M_b / l$$

used in stirring engineering was employed as a basis for determining the hydraulic radial forces acting on the stirring element.

This equation was also applied as a standard equation for reversed calculation, i.e., the determination of the bending moment for the purpose of calculating the agitator parameters. In this operation, F_R is not defined as a force but rather as an action of force applied on the bending moment. This definition may seem unusual if considered from the machine dynamics' point of view, but it may be explained by the fact that there is a general uncertainty in handling excitation forces for various types of stirring elements standardized on the basis of similarity laws, as well as in respect of the dynamic behaviour of rotors, taking into account the magnification function V_1, which is unknown in this special application because the amount of dampening is also frequently unknown.

Research target

The present research project is intended to make a contribution to creating a more detailed definition of factors influencing the bending moment, providing for a more precise calculation of agitator shafts to be used in any application required. The tests conducted on the agitators were evaluated, and loads and vibrations acting on the agitators were investigated by using the finite-element method (FEM).

Research results

Investigations were performed at an SNR agitator equipped with a dia. 40 x 3000 mm shaft and a dia. 400 mm propeller. The following are the most important results obtained:

- To assess the loading of the shaft by measuring methods, the measurement of the bending moment should be preferred to the measurement of the quantities of motion. For this purpose, a special measurement hub was developed. The measurement hub allows for conducting measurements at different shaft diameters by using an adapter.
- A calculation standard guideline was derived, and it was found that the magnification function as well as damping have an essential influence on the c_R values. In this connection, the determination of the actual damping values is of major importance.
- Calculation standards as used up to date result in stirring shafts that are over-sized in the supercritical area.
- Loads created by mechanical and hydraulic unbalances are small compared to loads generated by stochastically occurring hydraulic forces. The highest loads are generated by hydraulic forces acting in a long-term manner, in the course of several revolutions. Such forces also occur when elements are fully covered, especially in off-centre operation. Whereas measurements in the pit showed a quadratic increase of loading with rotational speed, it was found that off-centre operation produces an even higher gradient. To include these effects in a calculation standard, further testing series are required.
- FEM calculations illustrate the natural frequencies and their oscillatory shapes and furnish the following results, depending on rotational speed including critical rotational speed:
    - bending moments at any points of the agitator shaft,
    - bearing forces,
    - deflections of the shaft and of any other structural locations such as tank covers, centre of gravity of the motor, lantern, slide bearings.

The most important results obtained with the finite-element method are as follows:

- Natural frequencies are influenced mainly by vessel size, vessel wall thickness, stiffness of sealing, stiffness of bearings, and motor/gear mass.
- In the versions investigated, the centrifugal effect was negligible.
- The propeller blades are characterized by high stiffness and, consequently, high natural frequency. They do not influence the oscillatory behaviour of the rotor.
- If the agitator is rigidly fixed to a testing foundation, for example, the 2nd natural frequency is situated far above the working range (nkr2 > 900rpm). If fixed to tanks having a wall thickness of up to 4 mm, the 2nd natural frequency is situated inside the working range (nkr2 = 330 to 450 rpm). In such case, critical conditions may occur.
- Investigations by measurement resulted in a basic determination of both the quantities of excitation forces and the damping effect of the medium. Results obtained by FEM are therefore relatively comparable to each other.

Application and economic advantages

As mentioned earlier, the research project established a guideline for elaborating calculation standards. It is planned to conclude an agreement with Stelzer Rührtechnik International GmbH to continue the investigations with focus on investigations by measurement. Research efforts are undertaken to determine in more detail the loads acting on stirring elements under near-practice stirring conditions. The research work performed under this project should be continued as the measurements and calculations already performed constitute a well-founded basis for efforts still to be undertaken. The experience gained and the highly realistic FEM modelling work performed on the agitator are a sound basis for future work in this field.