Brüel & Kjær application notes

An introduction to modal testing

Modal testing has become an increasingly popular means of studying the dynamic behaviour of structures. Brüel & Kjær is committed to supporting high quality modal testing systems for solving problems and for optimizing resources in the engineering community.

We give here a simple description of modal testing followed by a discussion of some of the many applications of modal testing techniques. Finally we give a description of Brüel & Kjær modal testing systems based on our Dual Channel Signal Analyzers Types 2032 and 2034.

Brüel & Kjær supplies a wide range of equipment for modal testing. The many different applications of modal testing include trouble-shooting noise and vibration problems, design optimization, structural monitoring, and the verification of analytical models of structures

What is modal testing?

The sound we hear from a bell is due to the *resonances* and the radiated sound resulting from high vibration energy at resonant frequencies.

We can describe the dynamic behaviour of any *linear* mechanical structure in terms of parameters which describe its structural resonances. These *modal parameters* are the resonant frequency, the damping at the resonance, and the vibration pattern (*mode shape)* for the resonance.

The mathematical model based on these parameters is a linear model giving a complete description of the linear behaviour of the structure. Modal testing, then, is a class of experimental methods which determines a system's dynamic characterisitics and defines a dynamic model of a structure.

In modal testing we use a number of different measurement and analysis techniques of varying sophistication. The choice of technique depends on:

- The type and size of the structure.
- The extent to which the structure behaves linearly.
- What the test will be used for.
- The time and resources available.

What is modal testing used for?

Since the result of a modal test is a mathematical model of the dynamic behaviour of the structure under test, we can *simulate* the vibration response due to some forces which we assume could act on the structure in its working environment.

We can also use the model to simulate *modifications* to the structure to obtain the modal parameters of the modified structure. We define such modifications in terms of mass addition or subtraction at certain points, or by the addition or subtraction of stiffness or damping between points. We can then simulate the vibration response of the modified structure.

If we make modal tests on different substructures (or components), we can use the models to discover how the assembled structure will behave.

The many different applications of modal testing include:

Trouble-shooting noise and vibration problems. First we find the source of the problem by using vibration measurements on the structure under operating conditions. If the problem is caused by a structural resonance (in fact a structural weakness), we can apply modifications to the dynamic model and find alternative ways to remedy the structural weakness.
Design optimization. Tests on prototype structures allow us to optimize designs by simulating the response of the prototype, and making modifications to the dynamic model.

Structural monitoring. The modal parameters can be used to monitor the condition of structures. As defects or imperfections such as cracks develop, one or more of the modal parameters of the structure will change.

Verifying analytical models. We can use analytical models (derived through theoretical as opposed to experimental techniques) extensively in the early design stage of aircraft, spacecraft, and most other vehicles. These models, usually obtained through the finite element technique, are also used for simulation and optimization. Once we have built a prototype structure we do a modal test and compare the resulting model with the analytical model. This comparison then allows us to verify or improve the analytical model.

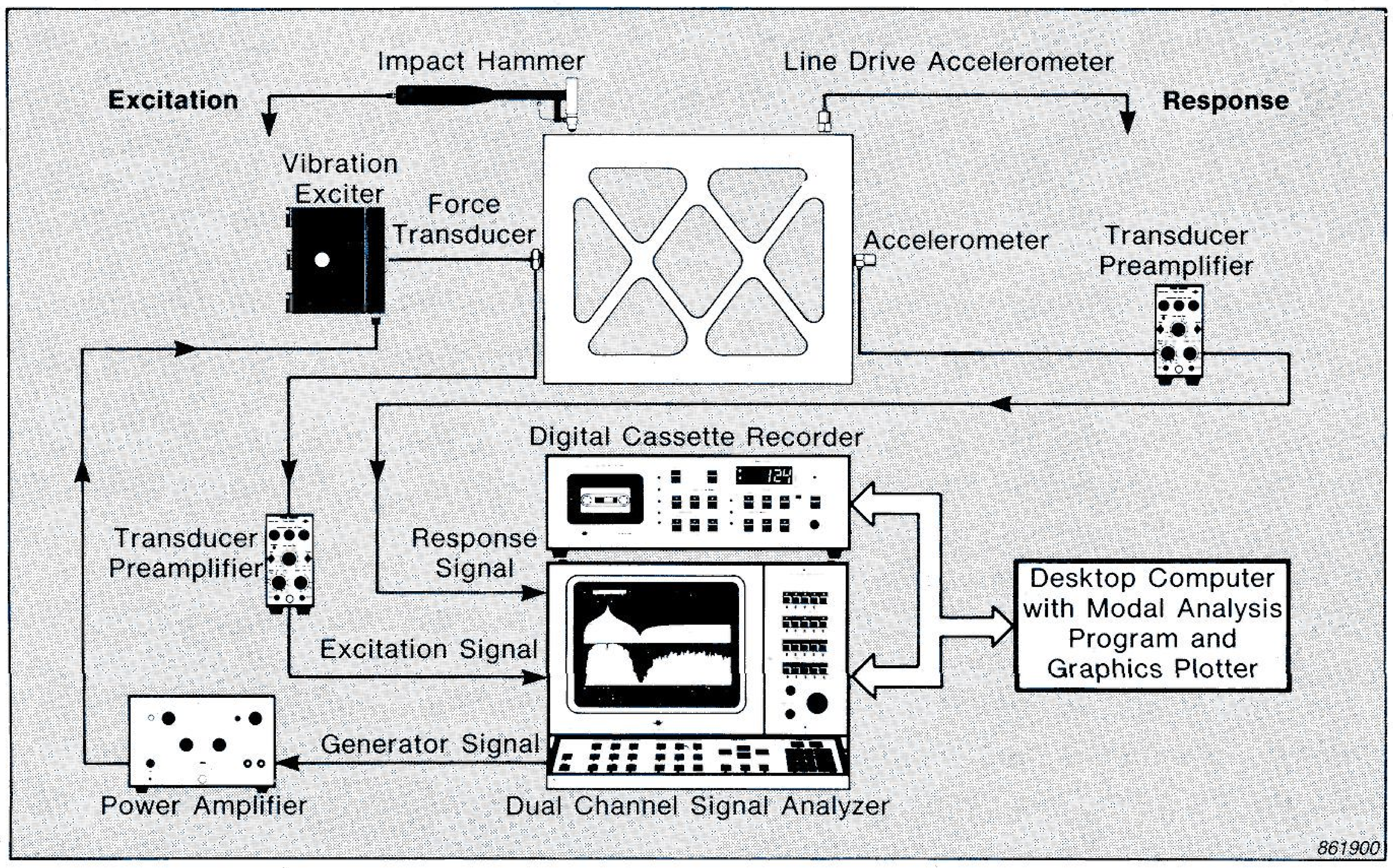

Fig. 1. Brüel & Kjær modal analysis systems are based on Dual Channel Signal Analyzer Types 2032 and 2034. There is a wide range of equipment for testing small and medium sized structures

How do we perform a modal test?

Since the accuracy of our dynamic model will depend on the accuracy of our measurements, it is important that we choose the best modal testing equipment available for the test.

Fig. 1 shows typical instrumentation for testing small and medium sized structures. We apply the excitation using an impact hammer or a vibration exciter. We measure the excitation and response waveforms by using a high quality force transducer and accelerometer respectively.

We measure the relation between the input excitation and the resulting vibration response between a selected number of points and directions. For this we use the frequency response function (mobility function). We can do this rapidly using a 2032 or 2034.

For some applications a simple technique known as "Quadrature Picking" is sufficient to obtain the resonant frequencies and unscaled mode shapes. However, for complex structures and where simulations and modifications are required, the modal parameters are obtained from the mobility measurements through a software program run on a desk top computer.

Fig. 2 is an example of a typical measurement made with a Dual Channel Signal Analyzer Type 2034 on a car mirror. From a number of these measurements the best fit to a linear mathematical model is derived giving the *modal model* containing the resonant frequencies, damping and mode shapes. Fig. 3 shows the mode shape for the third mode of the mirror.

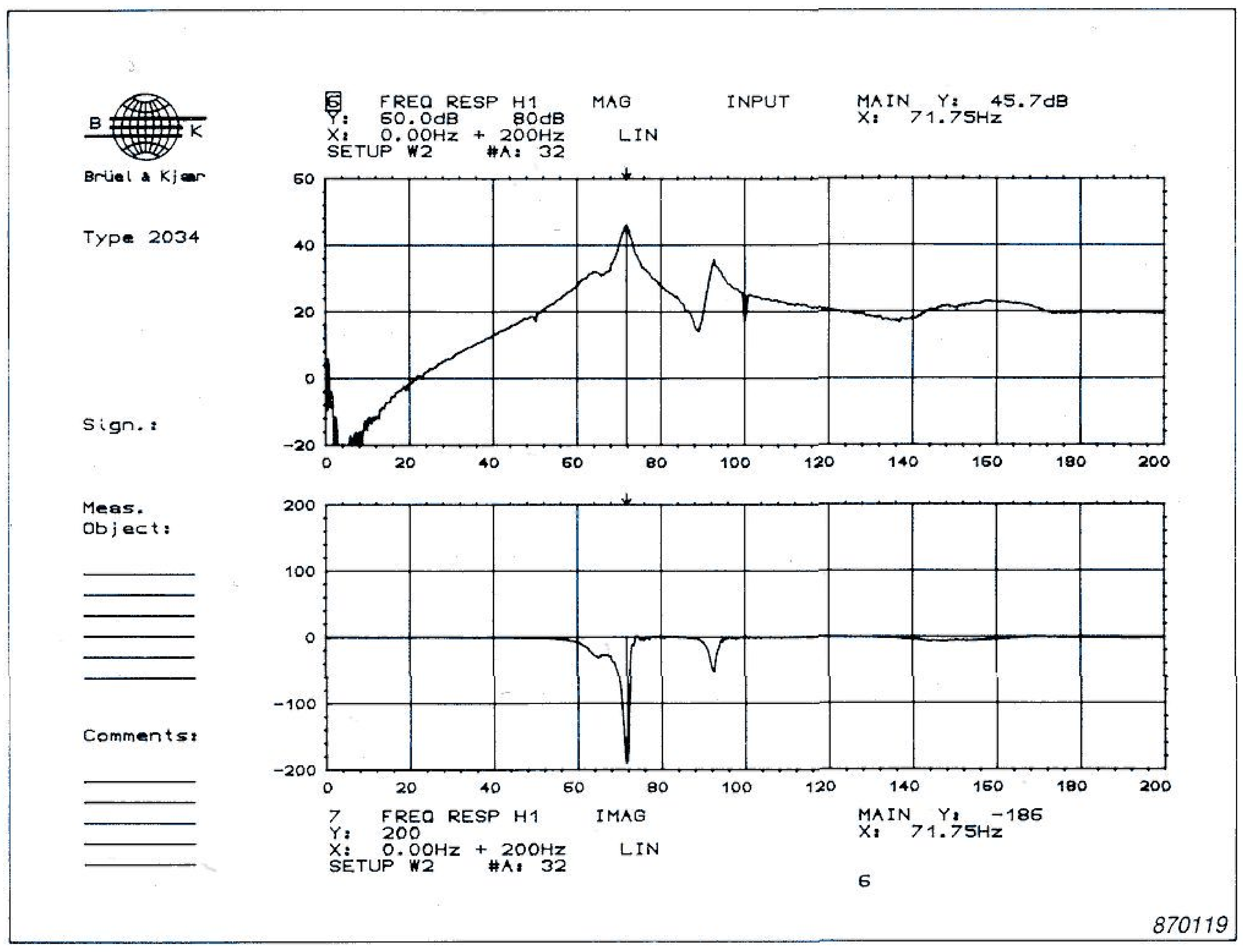

Fig. 2. Typical frequency response function from measurements on a car mirror. The magnitude and imaginary part have been selected for the upper and lower trace respectively. The plot was obtained from the Graphics Plotter Type 2319.

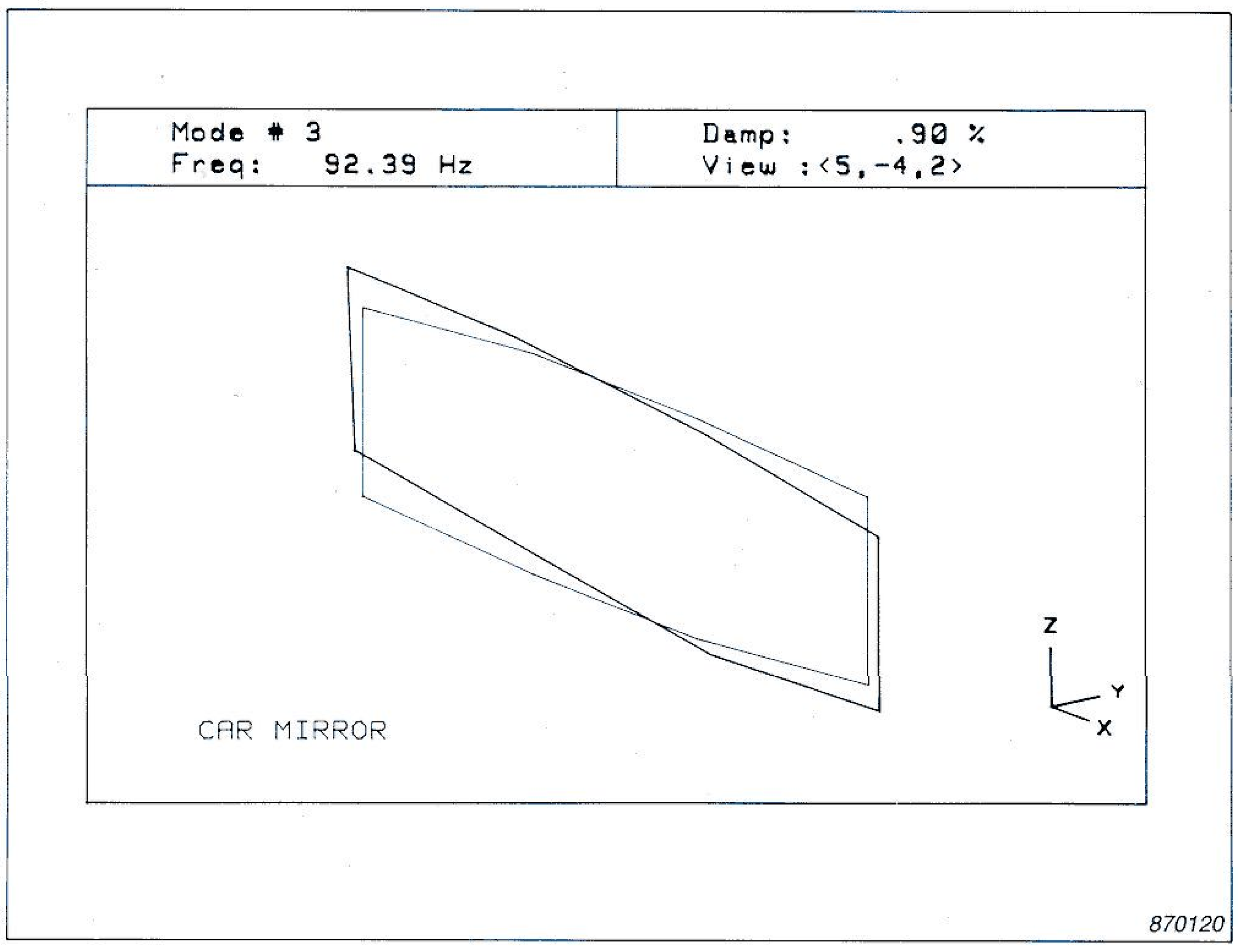

Fig. 3. The Brüel & Kjær Modal Analysis Software WT 9101 extracts modal parameters from the frequency response function. Here we see the third mode of vibration of the car mirror, superimposed on the undeformed structure.

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