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CRANK MECHANISM SIMULATION - A MODULE OF THE VIRTUAL ENGINE

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Summary: *In the powertrains of contemporary internal combustion engines, the crank mechanism maintains a dominant position. Exigencies laid on a crankshaft are usually very complex, the respective criteria varying also according to the type and use of an engine. In the course of many decades, calculation models of a crankshaft mechanism have developed according to current needs and possibilities of computer technology. In practice, simpler models for the solution of various partial problems have been used rather than complex models. This paper deals with contemporary possibilities of making complex three-dimensional powertrain models and it also presents a concrete example.*

1. INTRODUCTION

In the powertrain development process several numeric simulation techniques have continuously gained importance. The main target is the design support, which means help for design decisions. With the increasing power of computers accurate pre-calculations become possible with consideration of large number of effects and backward influences.

2. METHODS OF ANALYSIS

The Finite Element Method (FEM) enables to create solid FE-models of both a crankshaft and a cylinder block as shown in **Figure 1**.

These calculation models are very well applied to a modal analysis and solution of acoustic problems. The calculation of the structural transfer behaviour of single components is efficiently possible in frequency domain, using a linear approach and considering a large number of degrees of freedom. However, the interaction between parts of the engine is mostly not or just very roughly considered.

Multi-Body Systems (MBS) are, on the other hand, suitable for the calculation of the dynamic relations between single parts. Solving the equations of motion by iterative approach in time domain, the MBS-Solver are useful for the consideration of non-linear effects as well.

For the creation of a dynamic model of a crank mechanism, particularly 3-D beam whose nodes have six degrees of freedom seems to be a suitable element type [1]. The element has tension-compression, torsion and bending capabilities. Shear deformation is included in the element formulation. Some parts of a crank mechanism such as a flywheel, a pulley and a connecting rod can be modelled not only by beam elements but also by lumped mass elements. A different mass and moment of inertia may be assigned in each coordinate direction.

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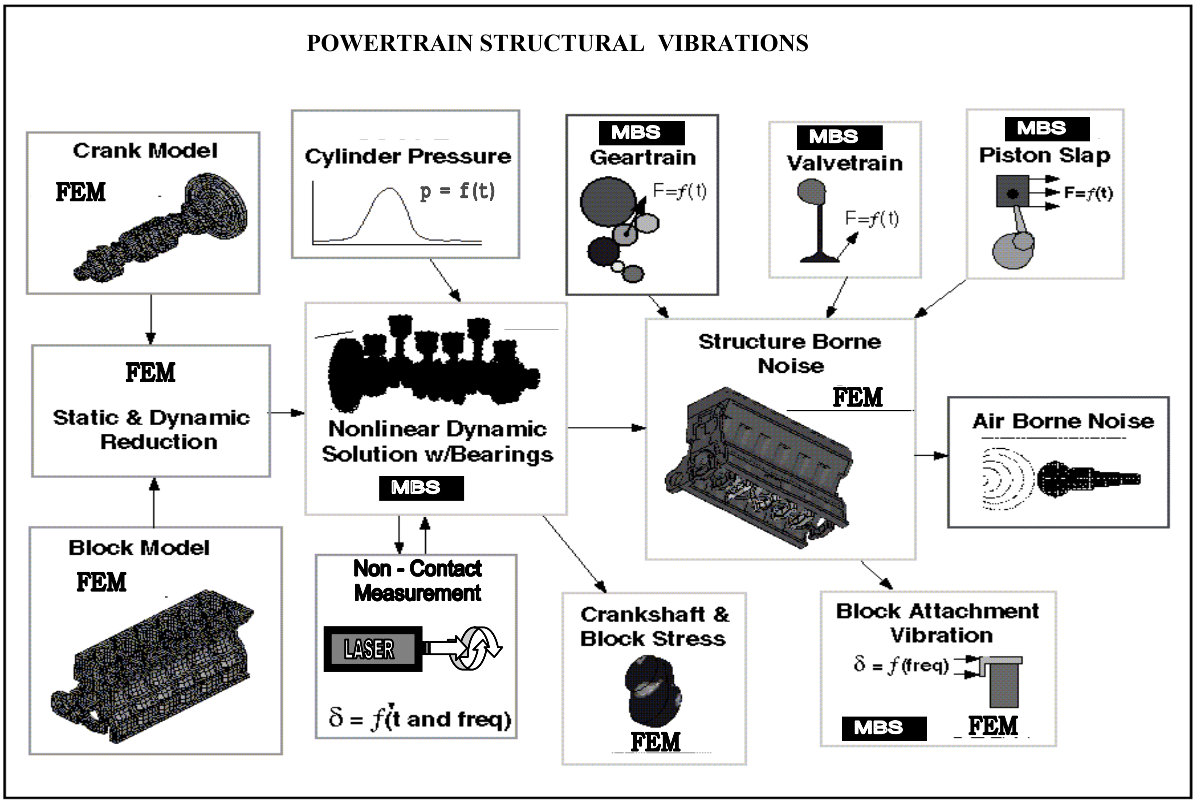

Figure 1 Modules of the Virtual Engine

Tuning of large mechanical structures is a rather difficult problem, which is known in particular from the field of experimental modal analysis [2], [3], [4], [5]. Regarding the fact that at the design stage of a cranktrain a crankshaft is usually not at disposal for needful measurements, it is necessary to realise the tuning of a beam mass model of a crankshaft in a different way.

The conversion starts with the calculation modal analysis of a 3-D solid model of a crankshaft from which the needed number of natural frequencies and appropriate mode shapes will be set. Subsequently, the tuning of a beam mass model is carried out with the calculated data. During this procedure it is not sufficient to compare the values of natural frequencies and control mode shapes visually. In particular more difficult mode shapes have to be controlled by using suitable criteria, for example, modal assurance criterion factors (MAC-factors).

In the case of the simulation of engine dynamics, hydrodynamic effects are very important. Especially due to the overconstained crankshaft the nonlinear transfer behaviour of the main bearings has a considerable influence on the distribution of the reaction forces. For the calculation of the radial plain bearing reactions several hydrodynamic simulation methods have been developed. Elasto-hydrodynamic techniques additionally consider the backward influence of local structural deformations of the bearing shell on the oil pressure.

Figure 2 illustrates a solid finite element model of a crankshaft of a six-cylinder in-line Diesel engine. This model was created by the method of solid modelling and it has 7736 elements and 10756 nodes. Its conversion into a beam mass model is shown in **Figure 3**.

The described 3-D beam mass model enables the calculation of dynamic components of motion, forces and moments of the crankshaft against the crank angle.

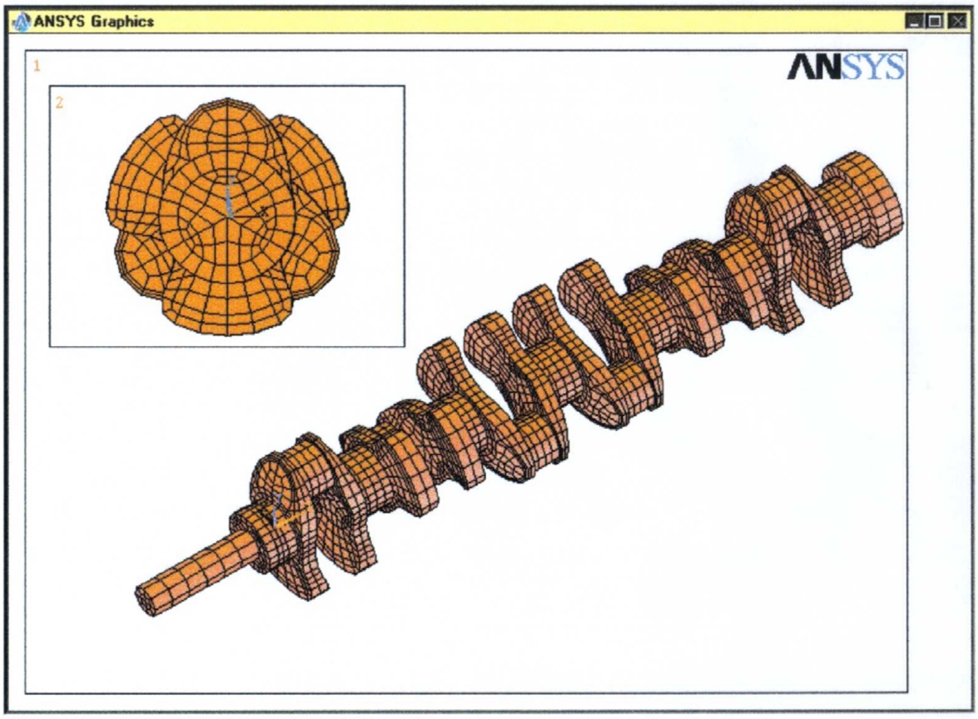

Figure 2 Solid FE-model of the crankshaft

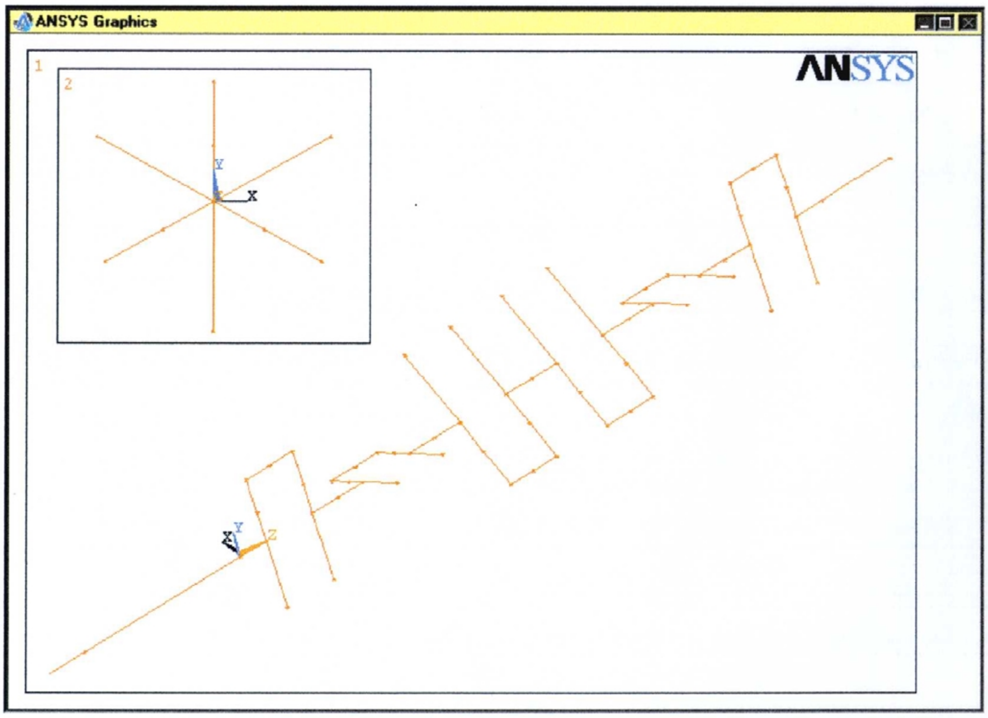

Figure 3 Conversion of the solid FE-model into a beam mass model

Crankshaft radial bearings and the thrust bearing have been modelled through the system of spring-damper elements whose parameters have been obtained from the hydrodynamic calculation (see **Figure 4**). The excitation loads acting on the engine were given by tangential and radial forces on single crank pins.

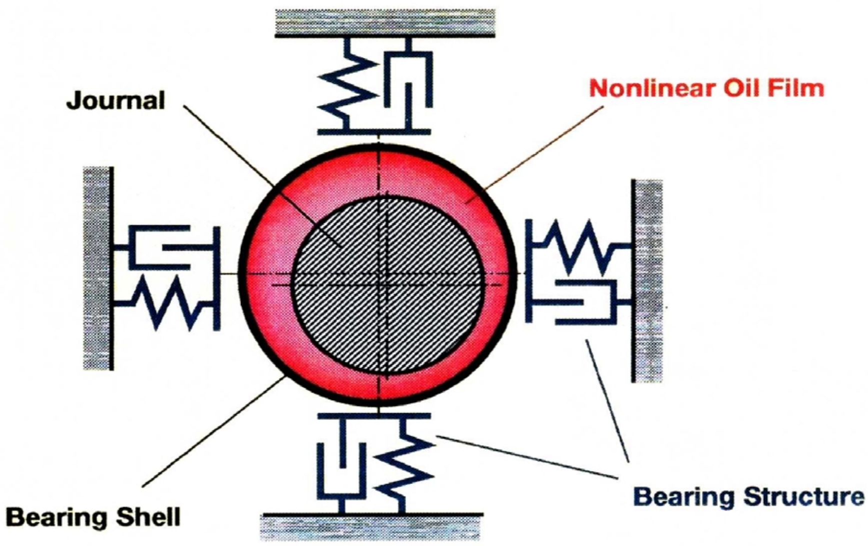

Figure 4 Spring-damper model of the main bearing

An example of such solution to the six-cylinder in-line Diesel engine crankshaft without a torsional vibration damper and with a rubber damper is illustrated in **Figures 5** to **8**.

3. CONCLUSION

The simulation of the crank mechanism dynamics is a central module of the Virtual Engine, which will be developed to a tool that makes it possible to calculate the total internal combustion engine mechanics and to support the design in the development phase.

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4. REFERENCES

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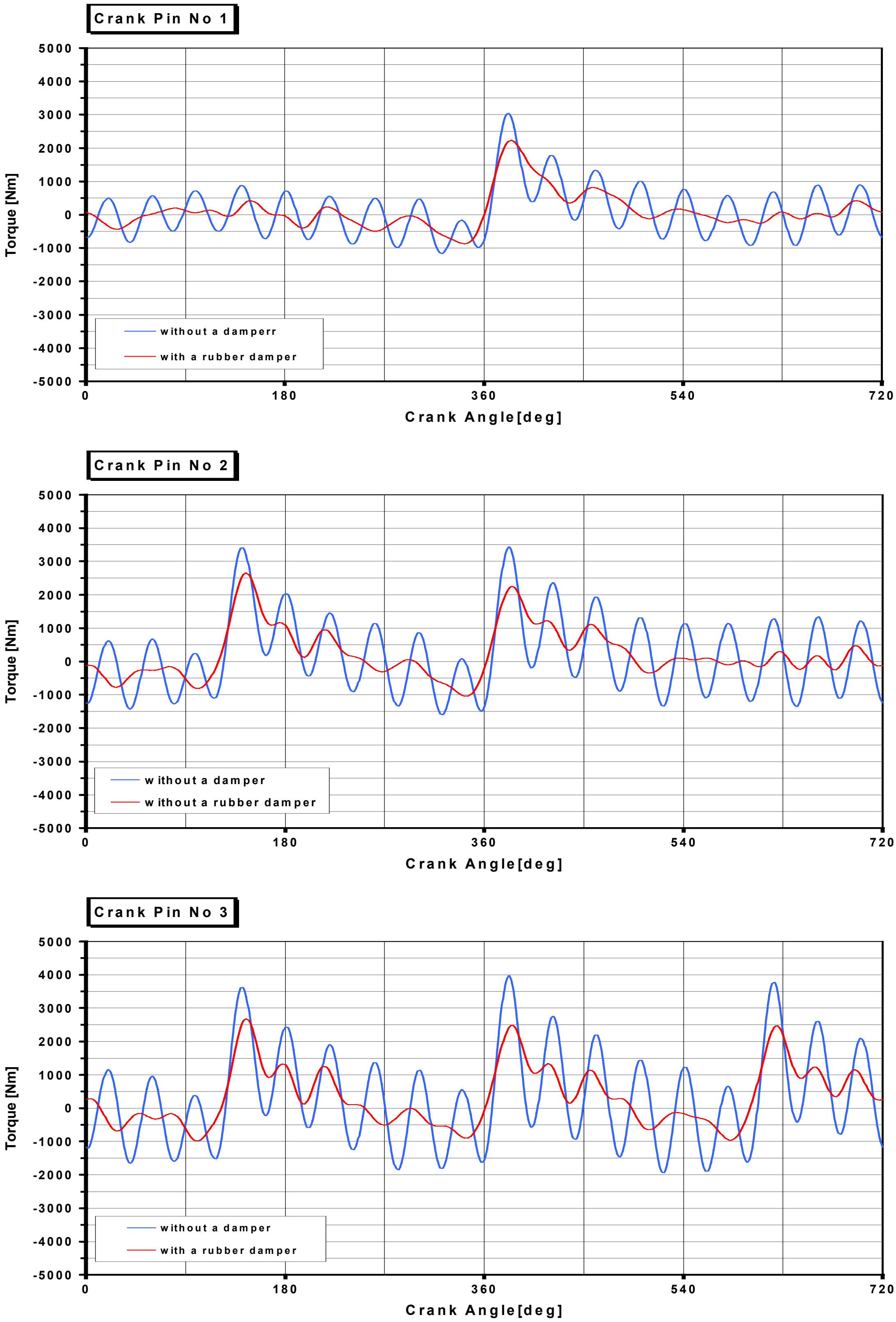

Figure 5 Torque at six-cylinder in-line Diesel engine crank pins at engine speed 1525 min^{-1}

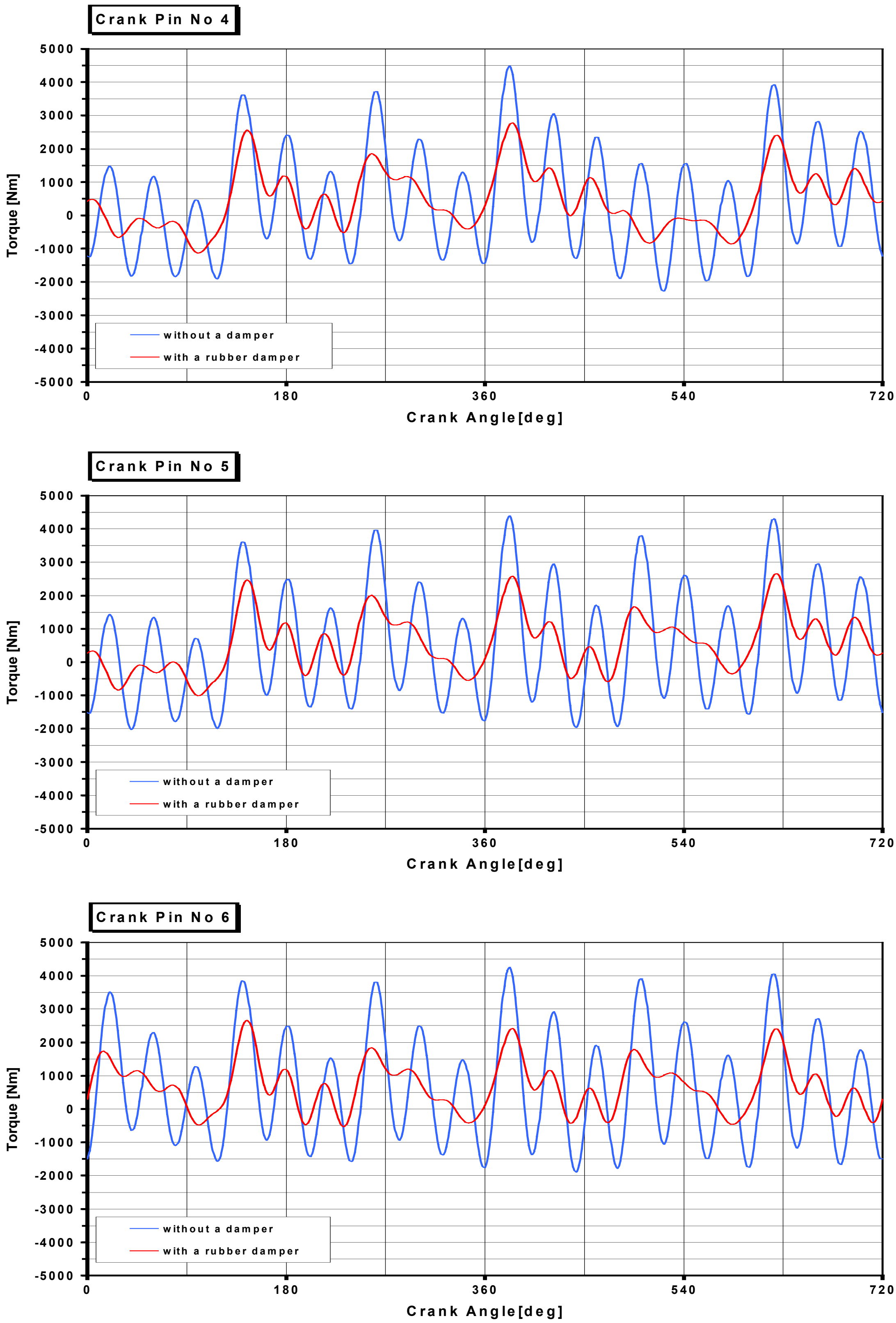

Figure 6 Torque at six-cylinder in-line Diesel engine crank pins at engine speed 1525 min^{-1}

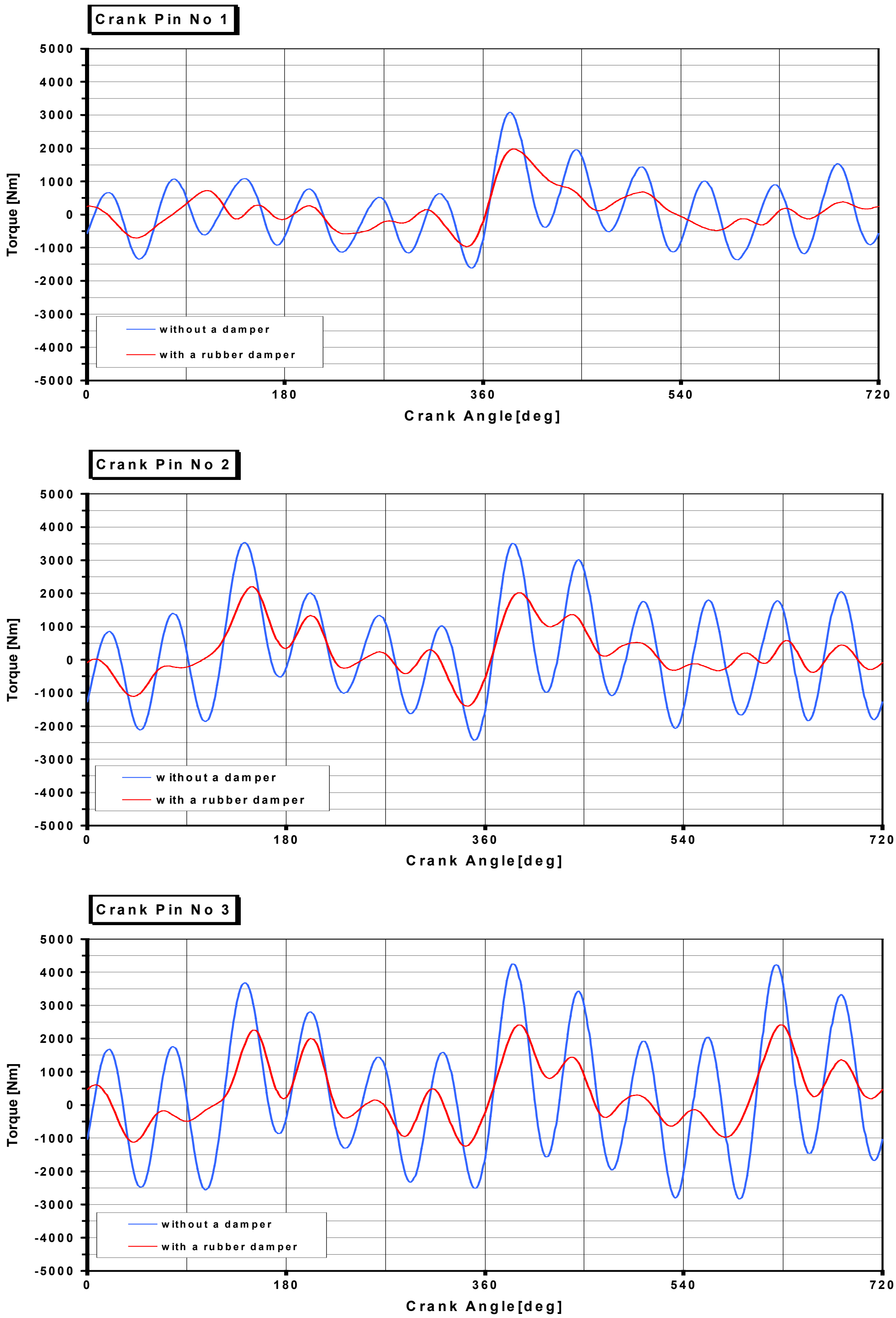

Figure 7 Torque at six-cylinder in-line Diesel engine crank pins at engine speed 2225 min^{-1}

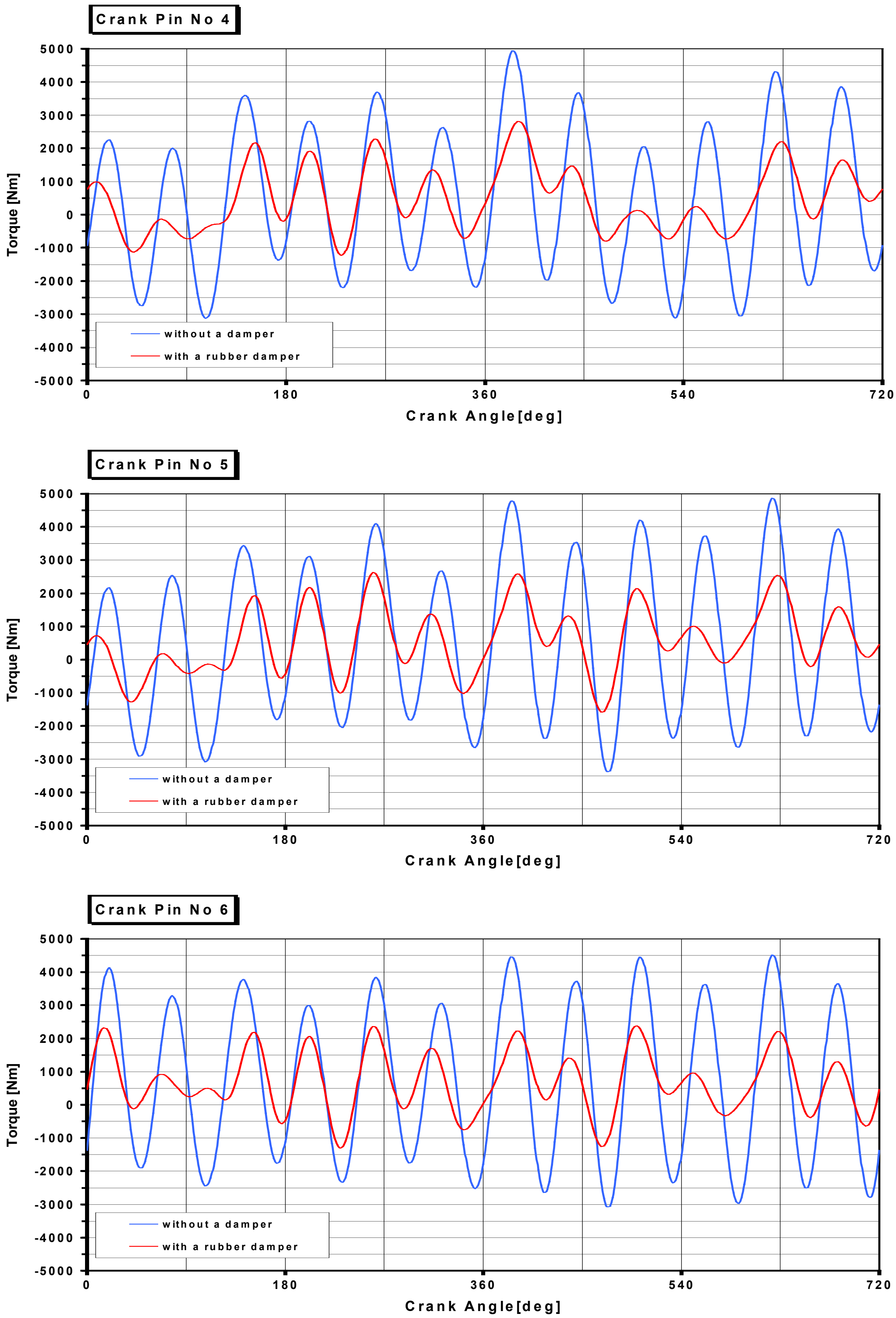

Figure 8 Torque at six-cylinder in-line Diesel engine crank pins at engine speed 2225 min^{-1}