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Special FE techniques in analysis of dynamics of aerospace structures

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ABSTRACT: The paper presents some chosen aspects of thermo-mechanical analyses, required to be conducted in the procedure of certification of spacecraft structures and measurement devices. Among typical investigation problems of structural thermoelastic behavior, verification of eigenmodes and eigenfrequencies, there are also more advanced analyses as sine-sweep (kind of specific frequency response) or even more "exotic" analyses as a response to random excitation or response to shock (impulse) load. These analyses are infrequent in regular mechanical (structural) analyses. Moreover, the structure of most space-dedicated elements or measurement devices is complicated and they are in fact assemblies of numerous "subsystems". That rises a problem of connection/interaction between these „subsystems". The strict requirements of the space authorities (NASA, ESA) exclude application of typical contact solutions. So especially in a dynamic environment the modeling is sometimes quite challenging. The paper presents examples of methodology and modelling approach applied in such cases.

KEY WORDS: random vibrations, shock, RBE3, CBUSH, bearings

1. General issues

The ESA-specific requirements of the analysis of the space exploration instruments are strictly defined in the ECSS (European Cooperation for Space Standardization) documentation. The ECSS standards define the details of analysis background. Some of the standard solutions defined by ESA require a sequence of FE analyses.

This sequence consists of some standard pre-run checks (Mass Property Checks, Gravity Load Checks, Rigid Body Frequency Check, Strain Energy Check, MAXRATIO and EPSILON Checks, Stress Free Thermo-elastic Check). Successful checks allow for analyses. The standard sequence consists of Static Thermo-elastic Analysis, Normal Modes Analysis, Random Vibration Analysis, Shock Analysis, followed by fasteners analysis (bolts etc.) and so-called Fail-Safe Analysis. The dynamic analyses of the instrument (Random and Shock) are pretty specific and require deeper knowledge of the background of the calculation.

The most important step is experimental verification of the Random and Shock behavior. The values predicted by the FE analyses must be matched by experiment results with sufficiently high accuracy.

2. Modelling of the analyzed assembly.

The most important feature of modelling according to ESA/NASA standards is proper modelling of the interaction between "subsystems" of the assembly. These connections are usually (in reality) designed as bolted connections, allowing for assembly and disassembly of the device during (or after) experiments.

Another specific feature of the space instrument is the bearing of the rotating "subsystems". Of course, quite other issue is the possibility of blocking/unblocking the rotation, lubrication issues and precise automatization of the rotation speed or angle controlling and verification. .

Due to the decades-long heritage and experiences in FE modelling gathered by NASA, and subsequently in large extent accepted by ESA, the standards FE code used for certification of numerical analyses is MSC.NASTRAN. However, the described in this paper solutions, used most frequently (named RBE2, RBE3. MPC or CBUSH in MSC.NASTRAN) are also accepted by other companies and available in commercial codes like ABAQUS, ANSYS or OptiStruct.

3. Bolted connection

The standard of the modeling the bolted connections in the space application is modelling the "pressure cone" application as RBE2 "spiders", attached to the "washer area" of the bolt or threaded portion of one part (magenta spider in fig.1) and corresponding part of the other connected part (green spider in fig.1). Important is also the CBUSH element (elasto-damping nonlinear element), connecting nodes of RBE2s. For numerical reasons the MSC recommendation is that CBUSH element should have ZERO length.

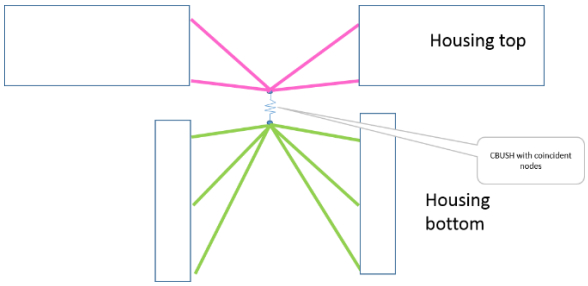

fig. 1. Bolted connection - two RBE2 plus CBUSH

4. Bearing systems

Modelling bearing of the rotating parts of the assembly brings the problem of proper interaction between tracks of the bearing (inner and outer), along with proper reflecting the flexibility/stiffness of the bolls/roller or the film of the bearing. These values, of course, must also reflect the preload values acting on the bearing. Typical model , shown in fig.2, consists of two RBE3 (interpolation elements), connected by zero-length CBUSH.

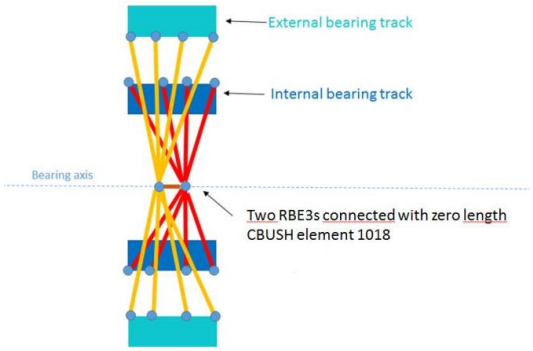

Fig. 2. Bearing model, two RBE3 and connecting CBUSH element

The illustration of a „simple" double bearing system is illustrated in fig3. It is pretty simple, only two bearing are used, and one of them (top one) is allowing axial play – what is provided by proper modelling of the CBUSH properties.

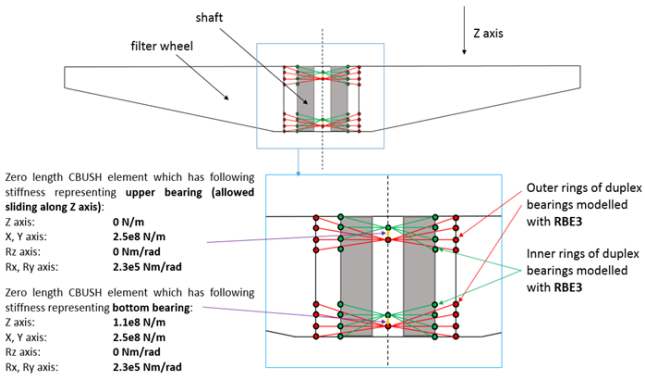

Fig. 3. Double-bearing system of the filter wheel – ATHENA mission

Definitely more complicated is the bearing-and contacting system for the PROBA3 FilterWheelAssembly (FWA) – see fig4. The "heart" of the assembly is the filter wheel (blue in fig 4) , driven by an electric motor that has

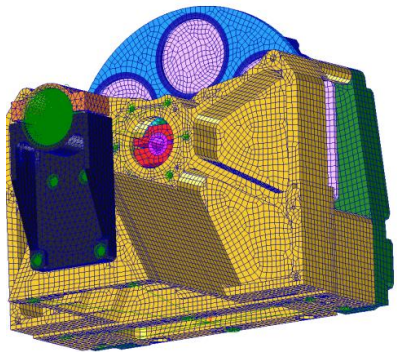

Fig. 4. FWA for ESA PROBA 3 mission

to move one of the filters built-in into the wheel into the optical line. The "drive-train" of the apparatus consists of: electric motor, shaft of this motor, the filter wheel shaft and elastic coupling of these shafts. What is obvious, the whole "drive-chain" is to be supported by a number of bearings, with proper preloads and proper properties.

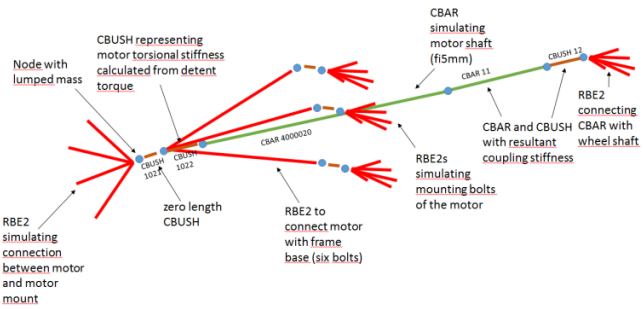

Fig. 5. Schema of the drive-chain of FWA with elastic shafts-coupling and supporting bearings.

5. Dynamic verification.

The properly built FE model is a source of defining the predictions for experimental verification. The Random and Shock analyses, performed either by direct or modal formulation, provide a location for application of the probes gathering data during the experiment. The accelerometers are the most common tool, although in some applications the laser measurement of dynamic behavior are also used. The successful correlation of the FE-results and experimental results indicate end of this stage of preparing the instrument for launch.

6. Summary

Proper FE modeling of complicated assemblies, with lots of bolted connections (hundreds!! of them), using different bearing systems is a hard task – but experimental verification allows for locating the problems and correcting both modelling and experiment setup, leading to successful realizing the investigated instrument as a "flight-ready".

Literature

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