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RESEARCH SHAKE TEST ON AN AIRBUS HELICOPTERS TECHNOLOGY DEMONSTRATOR

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Abstract: This paper comprises the work of the research shake test on an AIRBUS Helicopters full scale technology demonstrator. The test on the entire helicopter was performed by the vibration test team of the DLR-Institute of Aeroelasticity within three weeks in March/April 2023 at AIRBUS Helicopters Deutschland GmbH (AHD) in Donauwörth, Germany. In addition to the shake test, some specific test runs with the landing skid partially or fully on ground were also carried out as a preparation for the ground resonance tests in operation with rotor turning conducted by AIRBUS Helicopters.

The test specimen is a helicopter technology demonstrator. Like a ground vibration test on a fixed wing aircraft [1], the shake test shall provide the necessary experimental data to achieve permit to fly for the helicopter demonstrator. To this end, the test results shall enable the quantification of vibration transmission from main rotor hub to various positions on the fuselage, but also the adjustment of the dynamic models of the structure.

An equivalent modal substitute model was identified for the reference configuration. This modal model was established with a dedicated software and database which can be used for visualization and correlation of modal analysis results. This software can also provide scatter and nonlinear trends in modal analysis results. Next to the reference configuration, more than 20 other structural configurations have been tested, for which frequency response functions and specific modal parameters were provided in order to conduct experimental sensitivity studies.

The paper will focus on the hardware and software tools as well as the data analysis procedures applied during the tests.

1 INTRODUCTION

The shake test described in this paper has been performed within the German national aeronautics research project eVolve, in which Airbus Helicopters Deutschland (AHD) and DLR cooperate to improve tools and methods for helicopter aero-mechanics in the field of simulation and testing. The purpose of the shake test was to verify the effectiveness and accuracy of new analysis methods and new test hardware but also to provide the required experimental data to achieve the permit to fly for the test object.

The results of the shake test mainly comprise experimental modal parameters and frequency response functions for equivalent excitation on the main rotor hub and on the tail rotor. For the first time in such a test, the equivalent force and moments on the main rotor hub were calculated online from a real-time controller and were recorded together with the other response signals.

2 DESCRIPTION OF THE TEST SETUP

2.1 Test purpose and requested results

The shake test shall provide the necessary experimental data to demonstrate compliance with certification specifications, which require, that each part of the rotorcraft must be free from excessive vibration under each appropriate speed and power condition.

The main results of the shake test therefore comprise:

- Experimental modal parameters
- Frequency response functions for equivalent excitation on the main rotor hub and on the tail rotor

To achieve this, the tests have been performed in different payload and fuel configurations of the helicopter. In all related configurations, the helicopter was hanging from the main rotor hub in a dedicated test rig from DLR with soft pneumatic suspension. The frequency range investigated in the shake test ranges from 2 Hz to 50 Hz. It shall be mentioned that limitations in terms of maximum excitation forces and (frequency dependent) maximum vibration levels had to be respected during the test runs.

Further results were produced to support the experimental proof that the rotorcraft may have no dangerous tendency to oscillate on the ground with the rotor turning:

- Investigation of ground resonance stability

The aforementioned points are required for the permit to fly. Next to these, an additional task has been requested:

- Monitoring of static and dynamic loads in main gear box struts

The struts of the gear box are metallic rods which were instrumented with strain gauge full bridges. The strain gauges have been calibrated in advance by AHD. The calibration factors including the bridge offsets have been taken into account, which enables the monitoring of absolute strut loads. The monitoring of the main gear box loads was required to avoid disassembly and inspection of the struts after the shake tests.

2.2 Test boundary condition and helicopter configurations

For the shake test the helicopter was softly suspended at the main rotor hub in a dedicated test rig from DLR (Figure **2** and Figure **3**). In order to achieve low frequency rigid body modes, the test rig has a pneumatic spring system to hang the helicopter from the main rotor hub. The existing helicopter test rig of DLR was improved and completely redesigned for this test according to experience with shake tests on H135 and H145 using the old rig design, (see [2]). These modifications were designed to increase the rig stiffness, to extend the operating range of the pneumatic spring system and to enable fast changes between different test boundary conditions, i.e. helicopter softly suspended for shake test and landing skid on the ground for ground resonance shake test. The CAD model of the test rig is shown in Figure 1.

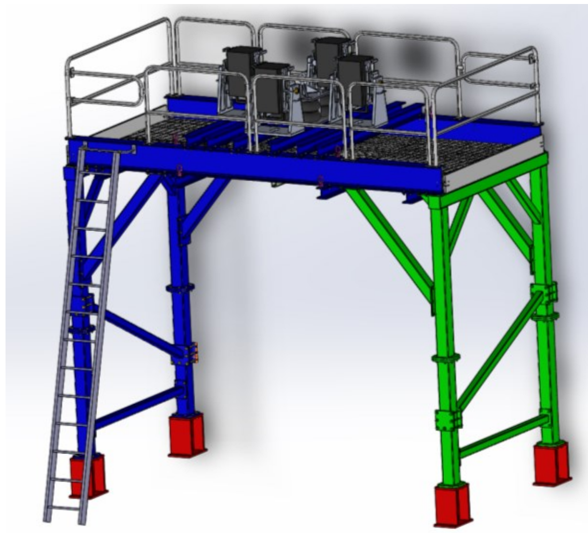

Figure 1: CAD model of DLR's revised helicopter test rig

For test operations, the rotor blades and parts of the main rotor hub are removed from the helicopter. Afterwards, a mechanical adapter (i.e. rotor cross) is installed on the main rotor shaft and mass dummies are attached to the adapter to represent a certain percentage of the rotor blade inertia. This can be seen in Figure 5.

The test rig has been improved in different ways to meet standards for safety at work but also to provide more space for test installation on top of the rig. One major improvement is the integration of four new long-stroke shakers on top of the rig with excitation direction pointing vertically downwards, see Figure 4. Together with a mechanical adapter installed on the main rotor hub, the four shakers can be used for pitch- and roll moment excitation and vertical force excitation on the main rotor hub. In order to avoid excitation of the test rig, the shakers are installed with vibration isolation.

Figure 2: Test setup front view

Figure 3: Test setup view from right side

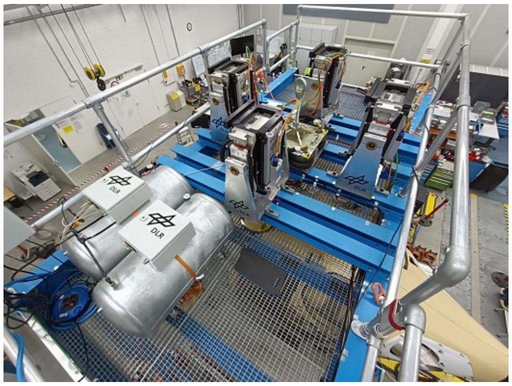

Figure 4: Installation on top of the test rig

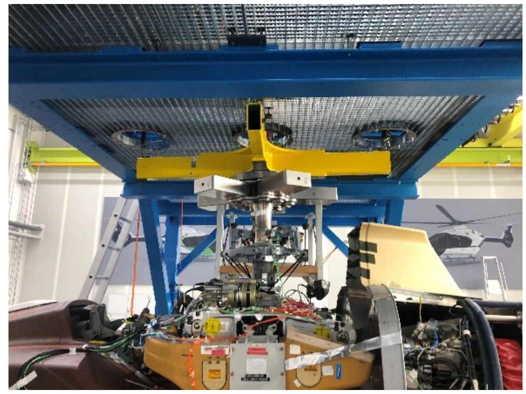

Figure 5: Rotor cross (yellow) side view

Another major improvement of the helicopter test rig is the pneumatic suspension. It is located in the middle of the upper deck of the test rig between the four shakers, see Figure 6. The suspension uses four pneumatic springs which are located on the corners between two stiff quadratic plates. The lower plate is connected to the rig, whereas the upper plate is suspended on the four pneumatic springs. The helicopter is connected to a threaded rod located in the middle of the suspension system. The lower end of the rod has a pinned connection to the main rotor shaft. The rough vertical positioning of the helicopter in the test rig can be adjusted with a nut on the threaded rod. This rod also enables to lift the helicopter i.e. with a crane.

In order to achieve low frequency rigid body modes of the helicopter, the pneumatic springs are connected to pressure vessels. The air pressure must be adjusted to lift the weight of the helicopter. The pressurized air volume of the vessels must be adapted to meet the requirements for low frequency rigid body modes. To this end, the pressurized air volume can be adjusted in discrete steps. Next to this basic functionality, the pneumatic suspension is regulated by a digital controller. The position and the pressure are measured and targeted suspension settings can easily be fine-tuned as compared to the analog controller used in the old test rig design.

Figure 6: Mechanical part of pneumatic suspension system

The pneumatic springs shown in Figure 6 allow for more displacement and provide a wider range of travel for the vertical positioning of the helicopter in the test rig as compared to the pneumatic springs of the former test rig design. The long stroke of the new shakers shown in Figure 4 allows for wider range of vertical positioning of the helicopter in the test rig as compared to the old shakers. In fact, the stroke of the new shakers is long enough so that the push-pull-rods connecting the shakers with the rotor cross can remain connected even when the helicopter is put back onto the ground. This was not possible with the old test rig design, where the shakers had to be disconnected from the rotor cross before putting the helicopter back onto the ground. This feature contributes significantly to efficient test progress.

2.3 Boundary conditions for additional ground resonance test

For the support of ground resonance tests, additional test runs were requested with specific boundary conditions of the helicopter:

- for classical ground resonance with (full) landing skid on the concrete floor (Figure 7)
    - main rotor excitation with force in x-direction (Tx) Figure 14 and with force in y-direction (Ty) in the frequency range from 0.5 Hz to 16 Hz
- for slope landing conditions the landing skid was only partially in contact with the ground (concrete floor). The front part of the landing skid was fixed to the ground (Figure 8)
    - main rotor Ty excitation in the frequency range from 0.5 Hz to 16 Hz

The Ty excitation was realized with a long-stroke shaker placed in a dedicated shelf hanging below the upper deck of the test rig. The Tx excitation was realized with a long-stroke shaker installed in a pendulum with reaction mass suspended from the hall crane.

For the fixation of the front part of the landing skid to the floor, a specific clamping device provided by AHD was used. The two clamps for the right and left skid were installed on a heavy steel bar.

Figure 7 Ground resonance test with skid on concrete

Figure 8 Ground resonance for slope landing

3 TEST EQUIPMENT AND TEST SETUP

3.1 Data acquisition system

The data acquisition system used in the shake test is a 496 channel Siemens SCADAS mobile system, see (Figure 9). The system is modular and is composed of six individual mainframes in master/slave configuration. The system features 480 standard input channels as required for acceleration sensors, force sensors or single-ended voltage signals plus 16 bridge module channels as required for strain gauge measurements. All channels are measured simultaneously and synchronously with an input range of up to ±10 V. The A/D conversion has 24-bits accuracy. All input channels are sampled with 51.2 kHz with adequate analog anti-aliasing filters. Specific sampling frequencies as requested by the test operator are realized by successive loops of digital filtering and downsampling (i.e. decimation) directly on the signal processors of the input channels inside the mainframes. Five mainframes are each equipped with 4 items of V24 II modules (24 channels each) which can provide signal conditioning for IEPE-type piezo-electric sensors and one main frame with two 8 channels bridge modules. Each frontend also has two output cards (QDAC modules) for a total number of 22 output channels for distributed signal generation e.g. to drive the shakers in the test rig.

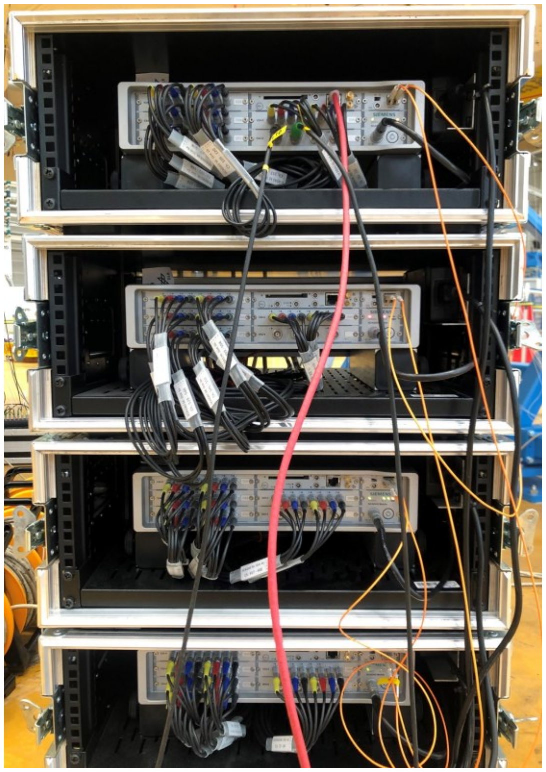

Figure 9 Siemens SCADAS mobile system

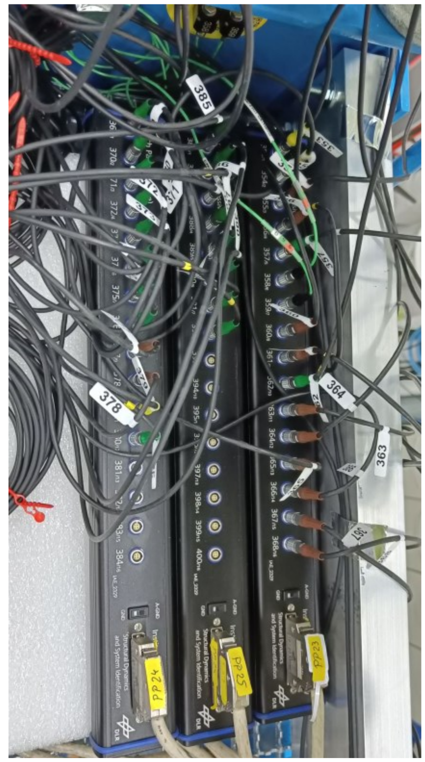

Figure 10 DLR-AE patch panels

DLR has developed special patch panels (Figure 10) to have well organized cable branches from sensors, via connecting boxes to the acquisition mainframes. This overall test setup is illustrated in Figure 11 using a fixed-wing aircraft ground vibration test as an example.

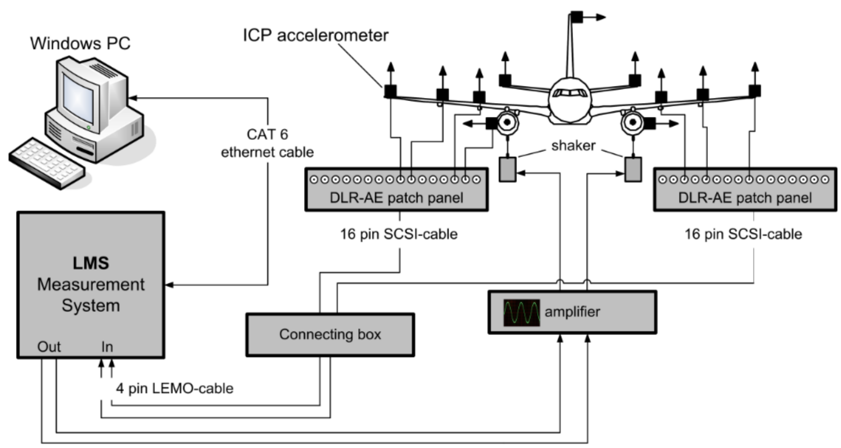

Figure 11 Principle sketch of measurement setup and organization of cable branches

The connecting box provides the adaptation from the 16 sensor signals of each patch panel available on SCSI cable to the 24 input channels of the V24 II modules in the acquisition mainframes. The connecting boxes are located in close vicinity to the acquisition mainframes. Input channels, sensor cables and sensors are labelled according to an internal numbering scheme. The internal sensor number matches with a specific sensor cable number. The specific cable is connected to the corresponding input channel number of the data acquisition system. The internal numbering scheme of all sensors and cables to match with the input channel numbers helps avoid errors in the physical test setup.

3.2 Acceleration sensors and force sensors

The type of acceleration sensor and force sensor used during this test were:

- KISTLER 8000M095 uniaxial acceleration sensor [4], 350 pcs. were used to measure the response of the structure
- PCB 208C03 force sensor, 8 pcs. were used to measure the input forces

The sensors (Figure 13) were applied to the structure by means of thin double adhesive tape. The sensors were not glued directly to the structure. Instead, a yellow sticker with measurement point information was applied to the surface of the test object and the sensor was attached with double adhesive tape onto the sticker (Figure 12). The stickers are printed with sensor ID, position ID and measurement direction. The metallic sensor element of the Kistler acceleration sensor can be rotated in its plastic housing to align the measurement direction to the global cartesian reference system. Furthermore, the plastic sensor housing prevents electric ground loops which improves the measurement quality and in particular the signal to noise ratio.

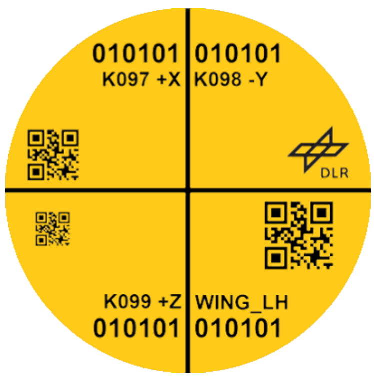

Figure 12: Sensor point sticker

Figure 13: Accelerometer installed

3.3 Excitation system

Excitation forces are introduced at the main rotor in vertical and horizontal direction. Forces in the vertical direction on the main rotor are introduced by 4 APS 420 shakers with a maximum force of 900 N and a maximum stroke of 150 mm. The overall weight of each shaker is 140 kg. The forces in the horizontal direction are introduced with APS 400 shakers, see Figure 14. Their maximum force is 445 N and the maximum coil stroke is 158 mm. The weight of this shaker is 73 kg.

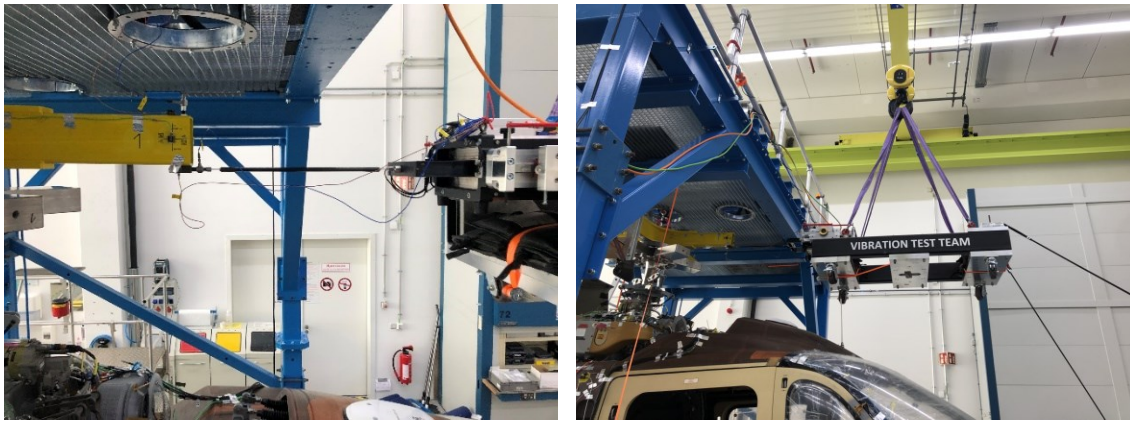

Figure 14: Excitation at main rotor in Tx direction with shaker and reaction mass hung from hall crane

At the tail rotor, exciter forces were introduced with PRODERA EX 220 C40 shakers. They have a maximum force of 220 N and a maximum coil stroke of 44 mm. The overall weight of the shaker is 20 kg. For the positioning of the shakers at the tail rotor hub and at the fenestron, tripods have been used. On top of the tripods, shaker support devices were installed which allow for rotation of the shaker and which provide vibration decoupling between shaker and tripod.

3.4 Measurement positions

The sensor plan for the accelerometer installation is shown in Figure 15. Acceleration responses were measured at 169 different locations with 356 measurement degrees of freedom. All the accelerometers were installed in the global coordinate system and are colored according to X, Y and Z with Red, Green and Blue arrows. Sensors are grouped according to the components of the test object on which they are installed. The components comprise the Landing Gear, Bottom Shell, Fuselage Rear Part, Cabin Frames, Main Gear Box, Engines, Tail Boom, Test Rig, Air Suspension, Rotor Cross Adapter, etc.

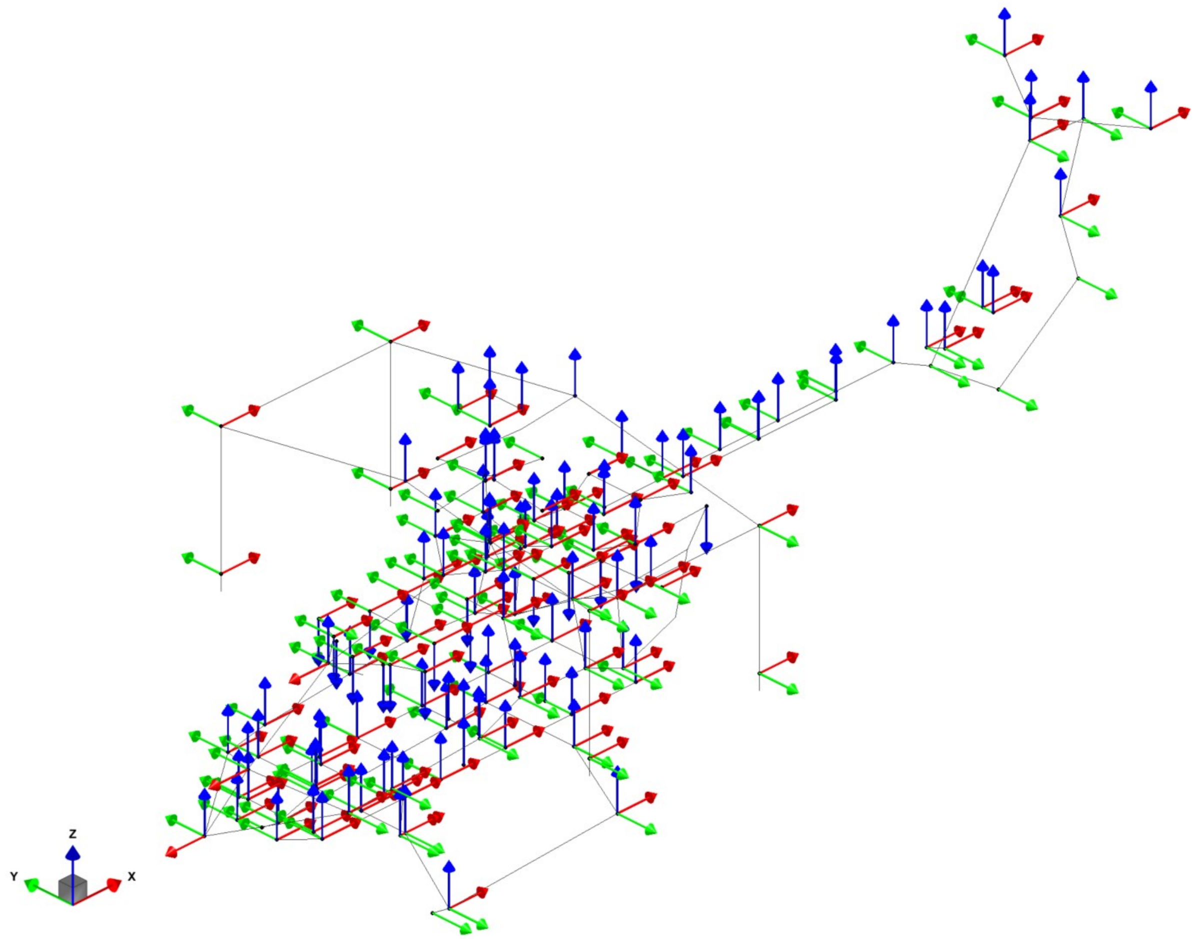

Figure 15 Overview of measurement point positions on helicopter and test rig

4 SHAKE TEST EXECUTION

According to the test purpose from chapter 2.1, vibration transfer functions must be obtained for excitation on the main rotor in Tz, Tx, Ty, Mx and My directions. Furthermore, transfer functions for excitation on the tail rotor in Tz and Ty direction have been obtained. The corresponding frequency response functions (FRFs) from these excitations can be used for quantification of vibrations for the fulfillment of §251 "Vibrations". Furthermore, the corresponding FRFs can also be used as input data for experimental modal analysis to identify the modal parameters of the helicopter. However, for modal identification the excitation on the main rotor hub is not always best suited. Therefore, additional excitation points were chosen on the landing gear attachment points in Tz and in Ty direction to ensure that all mode shapes are well excited.

Since force limits and vibration limits had to be respected, FRF measurements have been conducted on different levels. Random excitation runs and swept-sine excitation runs were performed. The random runs were necessary to gather a fast overview over the dynamic characteristics of the structure from a given excitation point without the risk of over-testing the structure by means of excessive vibration amplitudes. Swept-sine excitation was performed afterwards due to the outstanding signal-to-noise ratio of the response data. The sweeps were repeated on different excitation force levels. This allows to converge towards the given vibration limits which apply for the test. The force levels were not constant throughout the frequency range. Instead, force amplitude notching has been applied in order to meet the vibration response limits given for the test. The additional information provided by the FRFs from additional force levels is used to detect and quantify non-linear behavior of the structure.

4.1 Procedure for obtaining equivalent single-point FRFs from multi-point excitation on main rotor hub

During the shake test, multi-shaker excitation has been applied at the rotor cross installed at the main rotor hub. However, the transfer functions required for the quantification of vibration transmission shall be established for the excitation with a unit force or respective a unit moment at the main rotor shaft. Thus, a transformation from the multi-point excitation to an equivalent single-point force or single-point moment excitation at the main rotor shaft is required. In this section, the additional instrumentation and the data processing is described which has been applied to generate these equivalent single-point FRFs.

4.2 Determination of Equivalent Single-Point Excitation Force and Excitation Moment at Main Rotor Hub

The generation of equivalent single-point FRFs is required for the following excitations on the main rotor (MR) hub:

- MR – Tz-direction ($F_{ref,Tz}$)
- MR – Mx-direction ($M_{ref,Mx}$)
- MR – My-direction ($M_{ref,My}$)

From a mechanical point of view, the determination of the equivalent single point force and moment is equal to the determination of the resultant force and moment at a reference point from a set of independent distributed forces. The geometry of the rotor cross is required in this analysis together with the proper numbering of the measurement points. For the numbering of the measurement points, the DLR internal convention for numbering and naming of components must be taken into account. The following sketch in Figure 16 clarifies the geometrical positions and the numbering of points on the rotor cross.

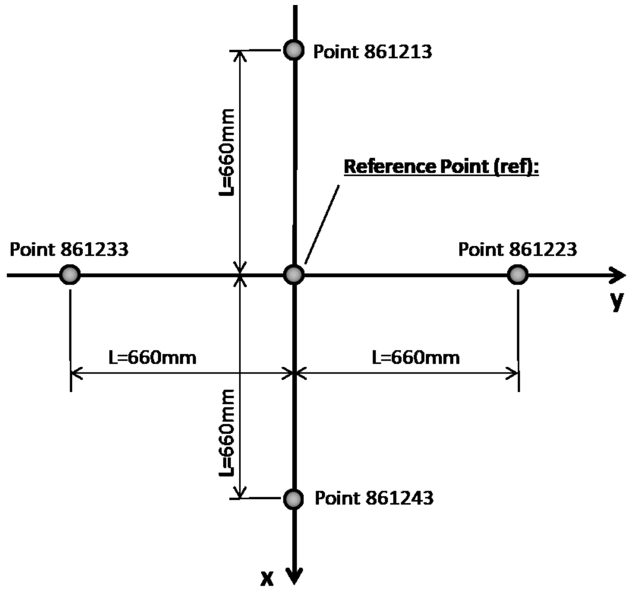

Figure 16: Geometry and measurement points on rotor cross

The following equations give an overview about the equations for the calculation of the equivalent force and moment at the reference point (ref) located on the axis of the main rotor shaft.

$$F_{ref,Tz} = F_{861213,z} + F_{861223,z} + F_{861233,z} + F_{861243,z} \tag{1}$$

$$M_{ref,Mx} = L \cdot \left(F_{861223,z} - F_{861233,z}\right) \tag{2}$$

$$M_{ref,My} = L \cdot \left(F_{861213,z} - F_{861243,z}\right) \tag{3}$$

For equivalent single-point FRFs, the equivalent response at the main rotor hub also has to be calculated. The equivalent driving point response comprises the resultant acceleration in z-direction, the rotational acceleration about the x-axis and the rotational acceleration about the y-axis at the main rotor hub. These three equivalent response quantities must be calculated from the four driving point accelerations at the outer exciter positions on the rotor cross. Unlike the calculation of the equivalent force and moments, the calculation of translational and rotational response at the reference point uses the assumption of a rigid rotor cross. This means that it is assumed that the response on the rotor cross in vertical direction changes linearly between the outer excitation points. The equivalent response quantities at the main rotor hub were calculate using the following equations.

$$U_{ref,Tz} = \frac{1}{4} \cdot \left(U_{861213,z} + U_{861223,z} + U_{861233,z} + U_{861243,z}\right) \tag{4}$$

$$U_{ref,Rx} = \frac{1}{2L} \cdot \left(U_{861223,z} - U_{861233,Tz}\right) \tag{5}$$

$$U_{ref,Ry} = \frac{1}{2L} \cdot \left(U_{861213,z} - U_{861243,Tz}\right) \tag{6}$$

4.3 Practical implementation of real-time computation of equivalent force and moments

In former tests, the equivalent force and moments on the main rotor hub were calculated offline after the test. With modern equipment for real-time processing of signals, it is possible to provide the equivalent force and moments in real-time. To achieve this, equations (1) to (3) and equations (4) to (6) for the equivalent single-point excitation at the main rotor hub were compiled into a Simulink model, see Figure 17.

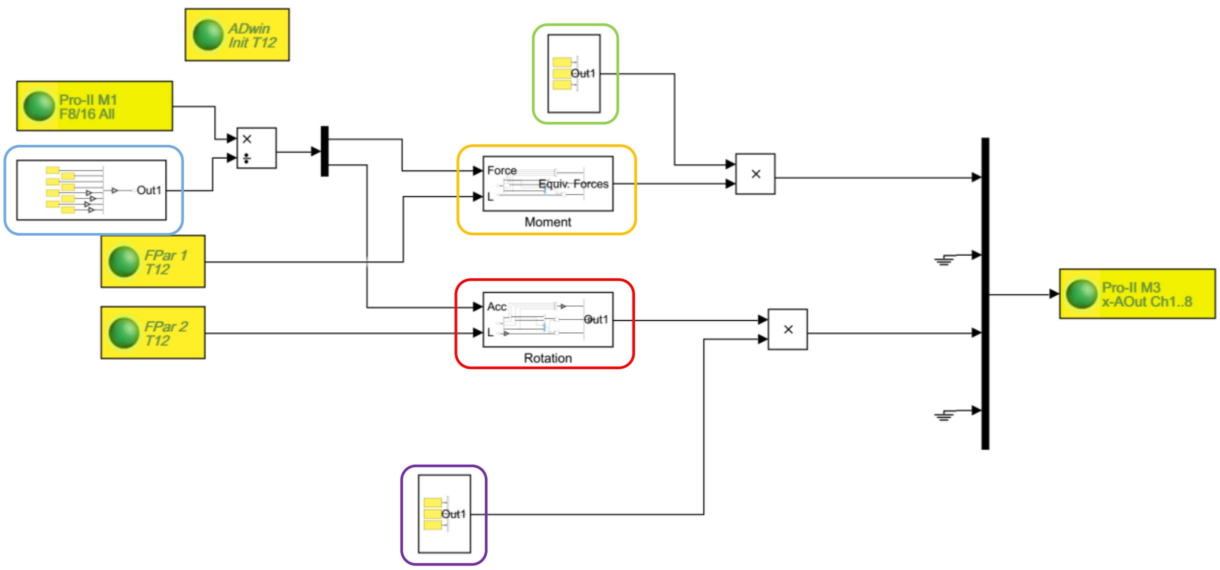

Figure 17: Simulink model for the real-time computation of the equivalent forces and moments at the main rotor hub (reference point) including equivalent driving point response quantities

Simulink models can be compiled and uploaded onto the real-time controller in order to solve the mathematical operations represented by this model in real-time. In this case, the ADwin Pro II hardware with the T12 processor was used. The installation of the real-time controller during the shake test. The Simulink model processes the signals from the driving point force and acceleration sensors of the rotor cross. These signals were recorded by the data acquisition system and at the same time, they were provided as input to the real-time controller. Next to the input signals, geometry parameters of the rotor cross, sensitivities of sensors and sensitivities of output signals must be provided for the computation. These parameters were however not embedded as constant parameters in the process, but were provided as functional parameters (FPAR) which can be entered and adjusted on a graphical user interface even during runtime (i.e. in case a sensor must be exchanged during the test or the levels of the output signals must be adapted). The output signals (i.e. the equivalent single-point quantities) were provided as additional signals to the data acquisition system. The Simulink model represents just a few algebraic equations. Therefore, the computational effort is rather low so that the process ran with a sampling frequency of 50 kHz. This leads to minimum delay time of 20 ns of the computed signals and thus negligible phase delay, see e.g. Figure 21.

4.4 Modal Correlation

The final step in the analysis chain during the shake test is the modal correlation of all modal result datasets that were produced by the modal analysis. Since different excitation positions can lead to modal result datasets containing identical modes identified with slightly different properties it is necessary to perform a systematic correlation of the result data sets to provide the best modal substitute model. To handle this task DLR developed an in-house software tool called “Correlation Tool” [5]. After the modal analysis the modal data and FRFs are transferred into a specific SQL database which is used by the Correlation Tool to load data, define relations between datasets and grant different user access rights.

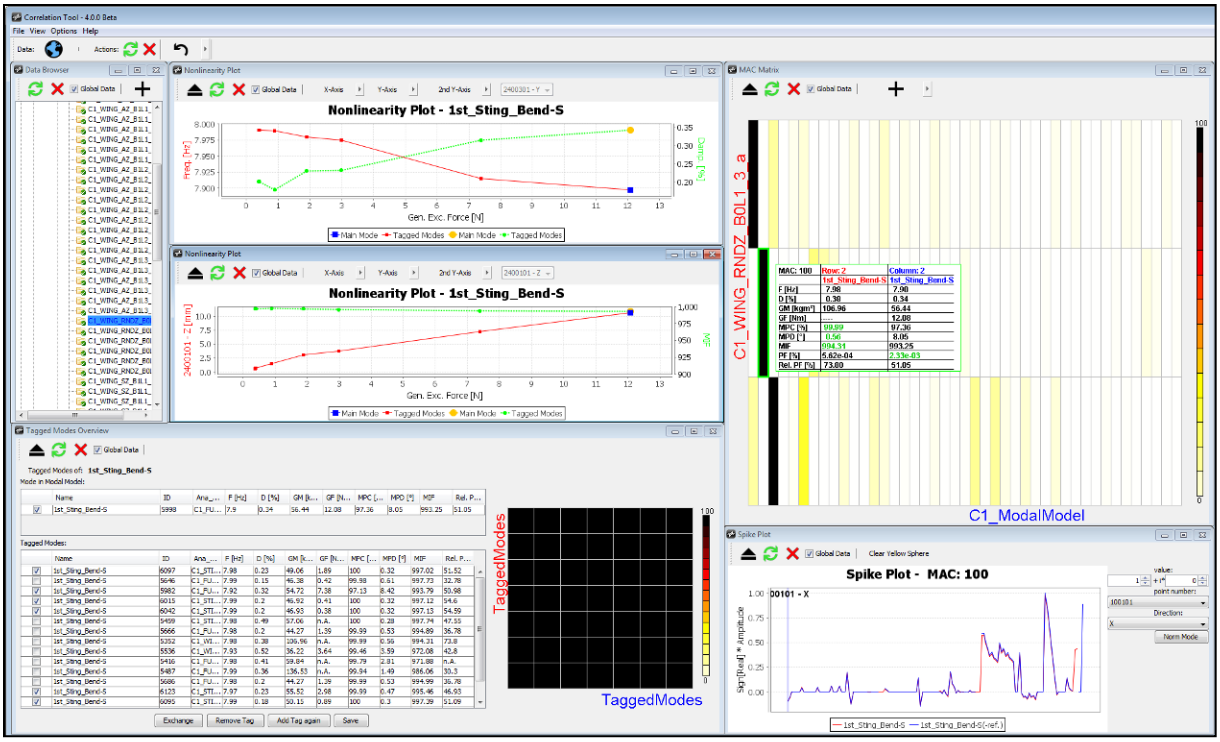

Figure 18: DLR Correlation Tool: view on first monitor

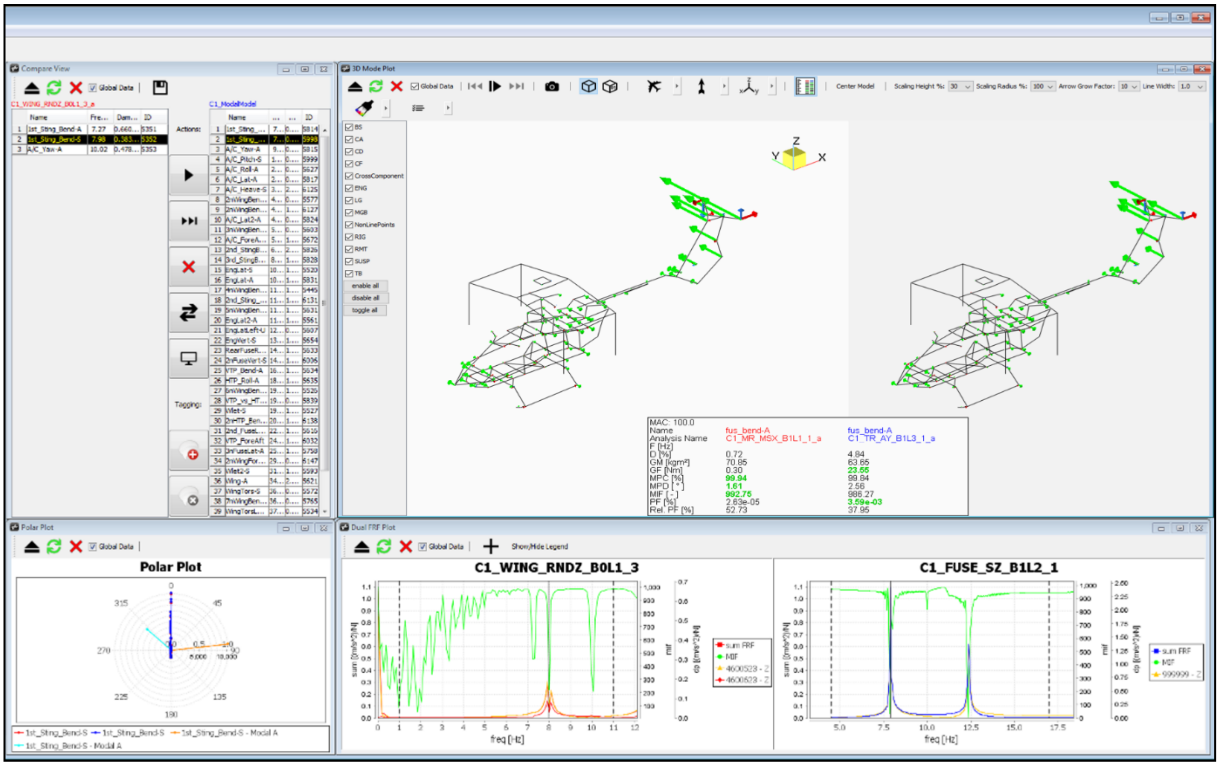

Figure 19: DLR Correlation tool: view on second monitor

In Figure 18 and Figure 19 an exemplaric view of the Correlation Tool is presented. The user has various different presentations of the available modal data like animated 3D plot, Polar Plot, Spike Plot or a Modal Assurance Criterion (MAC) Matrix between the current modal model and the modal dataset under correlation.

Usually the correlation process of a modal data sets starts by assessing the MAC Matrix and checking if a mode is already present in the modal model or not. If this is not the case the user can simply add the mode to the modal model, but if the mode is already available in the modal model the user has several options. The various different display options of the modal data helps the user to assess the identification quality of the mode by viewing the identification peak in the FRFs and MIF and several quality indicators like modal phase collinearity (MPC), mean phase deviation (MPD, mode indicator function (MIF) or generalized force (GF). After deciding which mode was identified with "better quality" the user can either add the mode to the family of its representative in the modal model or exchange the mode in the modal model and turning the new one into the representative of the modal family. This feature is possible due to the relations in the SQL database and is crucial for a good overview of a large result dataset. The mode families enable the user to have a quick overview of modal parameters of certain modes across all different excitation positions, to view the scatter in identified frequencies and damping ratios and check the linear behavior.

After correlating all modal result datasets, the modal model available in the database contains a linear independent set of modes where each mode is the "best identified" representative of its family. The definition for the "best identified" mode in the DLR philosophy is to use modes from excitation runs with high levels of excitation that result in high values of the generalized force parameter. A modal model assembled from these “best identified” representatives is considered to be the result of the test and is delivered to the customer.

As an additional feature of the user management of the database is to allow the customer read-only access to the database in order to use the Correlation Tool to have a look at the preliminary results during the test execution and to perform a correlation against numerical modes from the corresponding FE model.

5 RESULTS

The test rig introduced earlier was intended to allow fast changes between different boundary conditions. The softly suspended helicopter is verified by measuring rigid body modes, which must be well separated from the elastic modes. Figure 20 depicts the heave and the pitch mode which were between 1 Hz and 1.5 Hz. The frequency of the first elastic mode affected by those rigid body modes were at least more than three times higher. In fact, the acceleration sensors on the test rig show only minor response as compared to sensors on the vehicle. This demonstrates the desired functionality of the rig and the pneumatic suspension.

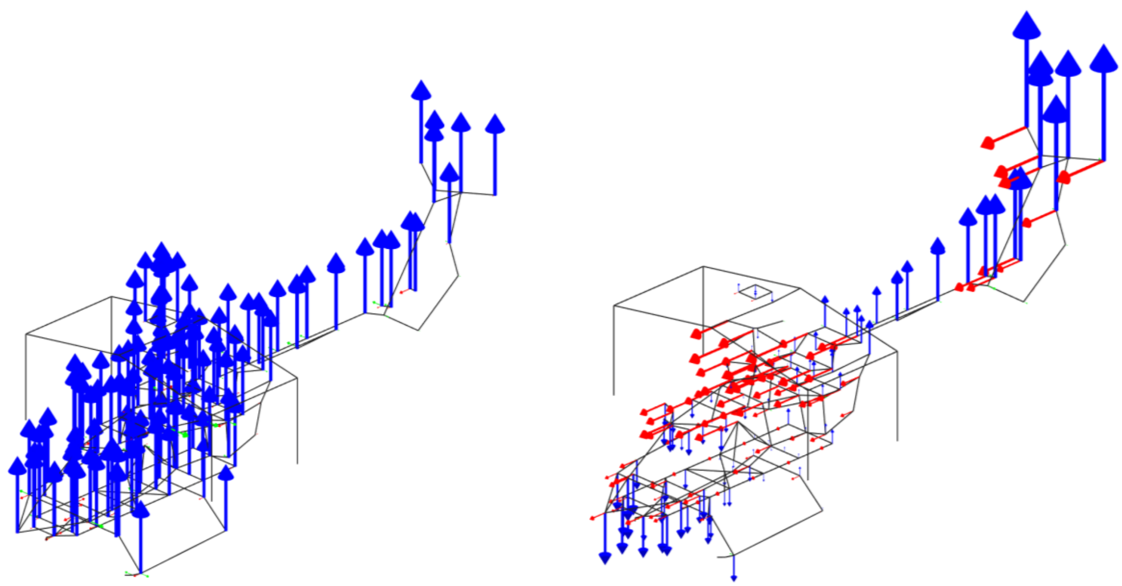

Figure 20 Heave and pitch mode

For the computation of the equivalent response to rotor hub excitation, moments and forces are computed in real time, so the actual moment at the hub could be monitored during measurements. Then the response can be referred to the virtual moments to compute the equivalent FRFs. Figure 21 presents the phase between response and excitation for the driving point. In case of the blue curve, the single virtual driving point method [3] is used and in case of the red curve, the equivalent FRFs are computed with the equivalent rotational acceleration and excitation moment. Both phase responses are in good agreement. The phase delay expected in the equivalent FRFs due to the additional computation in the real-time controller is thus negligible.

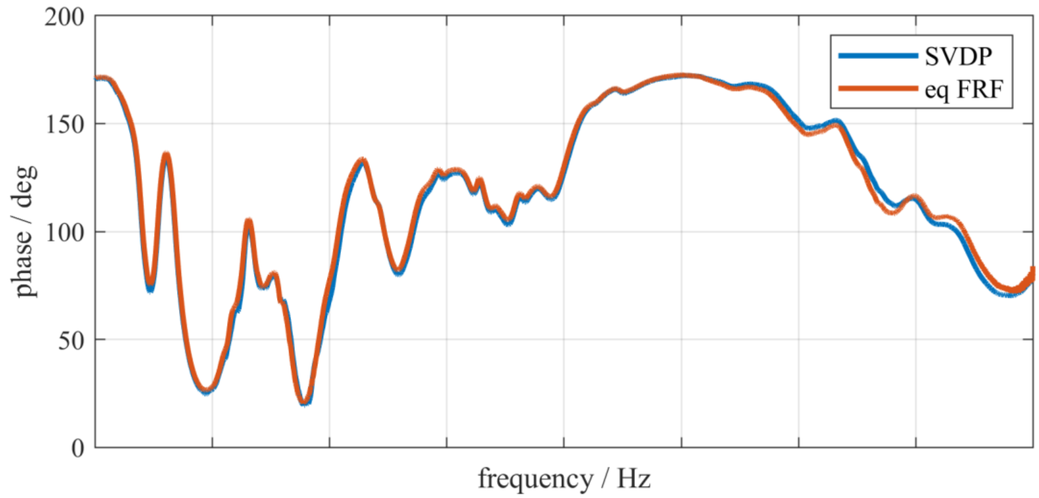

Figure 21 Phase comparison between SVDP and equivalent FRF

Another measure for the loading of the airframe is given by the strain measurements of the struts between fuselage and main gear box resulting in measured forces. Figure 22 gives an example of measured strain responses normalized to the respective mean value of each time response. After evaluation of the strut loads for each run, one could confirm that all loads were remaining within the limits planned in advance so that visual inspection of the struts after the test was not necessary.

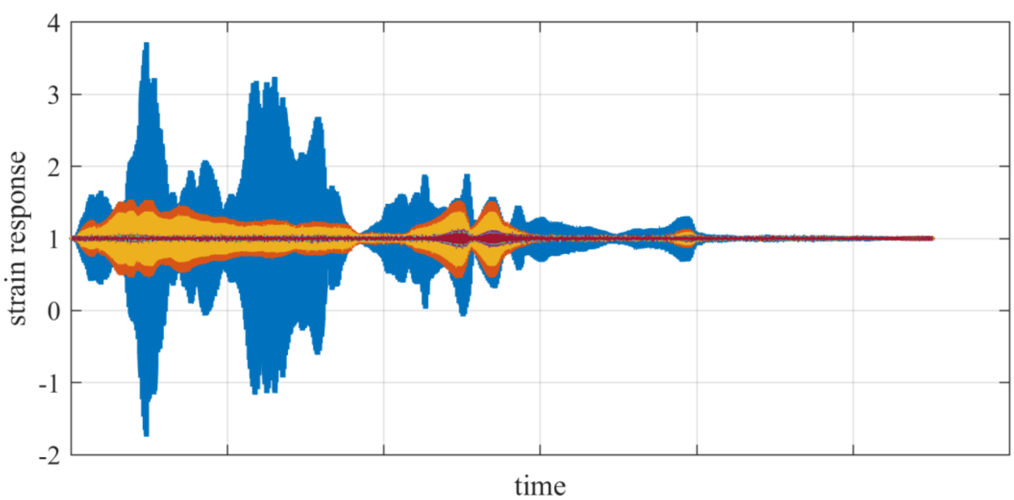

Figure 22 Time response of strain measurement normalized by mean value

The correlation tool presented in the previous section allows the test engineer to assemble a modal model for one configuration correlating all identified modes. In one configuration, for example, 490 modes were identified from all available FRFs and 47 modes were selected for the final modal model. Finally, the modal models of different structural configurations of the helicopter can be compared, as indicated in the MAC matrix of Figure 23. High correlation values on the main diagonal indicate mode shapes, which occur in both configurations. White spaces indicate however, that the related modes were strongly affected from the difference in the structural configurations.

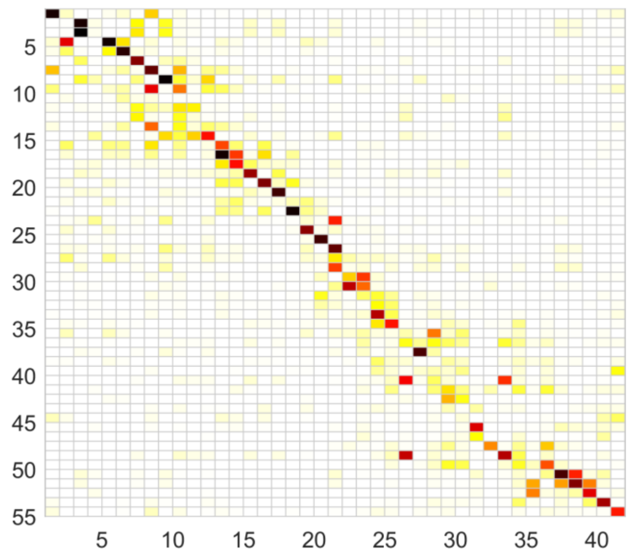

Figure 23 MAC matrix between two configurations

6 SUMMARY AND CONCLUSIONS

A shake test was successfully performed on an AIRBUS Helicopters (AHD) Technology Demonstrator. The test was performed at AHD in Donauwörth, Germany, in March/April 2023. The helicopter was suspended from the rotor hub inside a test rig with a pneumatic suspension system. Acceleration responses were measured at 169 different locations with 356 measurement degrees of freedom on all relevant components of the helicopter. Twenty-two configurations were tested with varying payload masses as well as structural modifications on the landing gear.

The excitation signals comprised random and sine-sweeps in the frequency range from 2 Hz to 50 Hz. The revised test rig with the improved pneumatic air suspension provided a good decoupling of the vibration modes of the rig and the rigid body modes to the elastic modes of the helicopter. The test rig enabled fast changes of test configurations, and to save test time and contributed to safer operation.

During the test, equivalent single-point excitation forces and moments at the main rotor hub were calculated online using a real time controller. The real-time controller delivered good results in the online computation of the equivalent forces and moments in real time with only a small and negligible delay, which, among other things, enabled reliable display and monitoring of the excitation moments during the ongoing measurement.

The monitoring of the strut loads was conducted without any difficulty. At the beginning of the test, it was discussed whether or not the absolute loads or the tared loads shall be measured. In the retrospect, the decision to measure the absolute strut loads was correct. Seamless monitoring of the loads was demonstrated and disassembly and inspection of the struts has been avoided.

A final modal model consisting of 55 unique modes was identified for the reference configuration. For the other configurations, the frequency range for modal analysis was shortened and the corresponding modal models comprise less modes. The DLR correlation tool provided the customer (AHD) with fast and efficient access to the test results during the test and thus enabled an immediate validation with the FEM.

After the shake test, AHD conducted the ground resonance test as can be seen in Figure 24. Finally, the helicopter demonstrator obtained permit to fly.

Figure 24: Ground Resonance Test of Helicopter Demonstrator

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