EN-MME Mechanical Measurements Lab Report

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Vibration failure analysis of LIEBE electromagnetic pump

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Summary

The goal of the measurement was to determine the levels of vibrations generated by an operating electromagnetic pump and the levels of vibrations transmitted to LIEBE setup. Data post-processing and comparison is performed in accordance with international standards for mechanical vibration of rotary parts (ISO10816).

1. Introduction

The goal of the test was to measure the levels of vibration transmitted from the operating electromagnetic pump to LIEBE setup (Figure 1), assuming its standard operation. For this purpose, several measurements have been performed on the whole setup at different rotational speed of the motor and for both coupled and uncoupled positions. The data obtained from those measurements was used for determining the levels of vibration on both the pump and the setup and for deciding if they are within the admissible limits according to ISO10816. This data is also used as a preliminary information before the installation of a permanent vibration monitoring sensors.

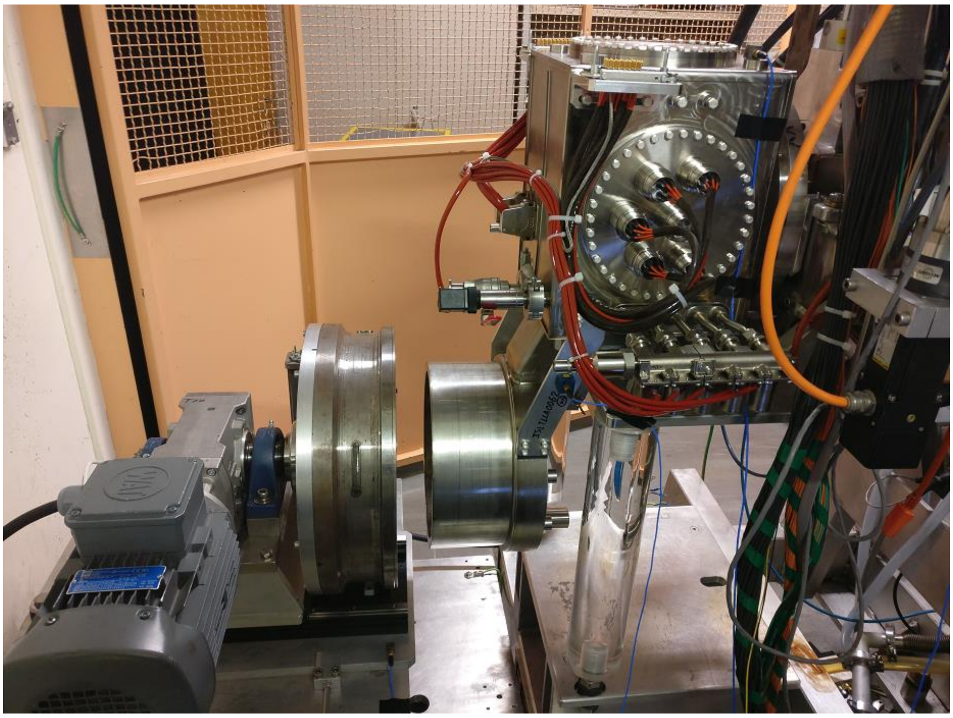


Figure 1 Motor and LIEBE setup

2. Measuring equipment and configuration

2.1. Sensors

For the purpose of measuring the dynamic response of the structure, five tri-axial accelerometers from PBC Piezotronics were used with sensitivity and frequency range as stated below:

	Type	Sensitivity	Frequency Range
A1	356A33	1.02 mV/(m/s^2)	2 Hz – 7kHz
A2	356A33	1.02 mV/(m/s^2)	2 Hz – 7kHz
A3	356A15	10.2 mV/(m/s^2)	2 Hz – 5 kHz
A4	356B08	10.2 mV/(m/s^2)	0.5 Hz – 5kHz
A5	356B08	10.2 mV/(m/s^2)	0.5 Hz – 5kHz

2.2. Calibration

Each accelerometer was calibrated using a handheld shaker. The handheld shaker supplies an acceleration level equal to 9.81m/s^2 at 159.2Hz. The accelerometer response is compared to the vibration shaker and the real sensitivity is determined.

2.3. Acquisition system

The acquisition system used for the measurement was MKII made by Müller-BBM. The MKII system is a real time spectrum analyzer and a compact data acquisition system. It contains 16 input channels with DSP (Digital Signal Processing) for each channel, with a sampling frequency rate up to 200 kHz. The dynamic resolution is 24 bits for ICP42 cards and 16 bits for ICP41 cards, and can be used in a range between 10 mV and 60 V.

Figure 3: MKII Spectrum Analyser

The system is controlled by PAK® Software, which allows to control the hardware that measures the signal and allows different post-processing functions such as FFT (Fast Fourier Transform), PDS (Power Signal Density) and CPS (Cross Power Spectrum) to be carried out.

2.4. Acquisition Parameters:

The parameters for the data acquisition were as given in the table below:

Table 1 Acquisition and post-processing parameters

Parameter and [unit]	**Value**
Sampling frequency [Hz]	2048
Max. frequency [Hz]	800
Frequency Lines	8192
Frequency resolution [Hz]	0.0625
Window	Hanning
Averaging	Linear
Acquisition time [s]	300

3. Measurement setup

The 5 3-axial accelerometers where place on the structure as shown in Figure 2. The 2 most important locations of the accelerometers in order to determine the transmission of vibration from the motor to the setup are shown in Figure 3. Those are: accelerometer A1 PUMP (left fig.) and A4 LIEBE_SIDE (right fig.)

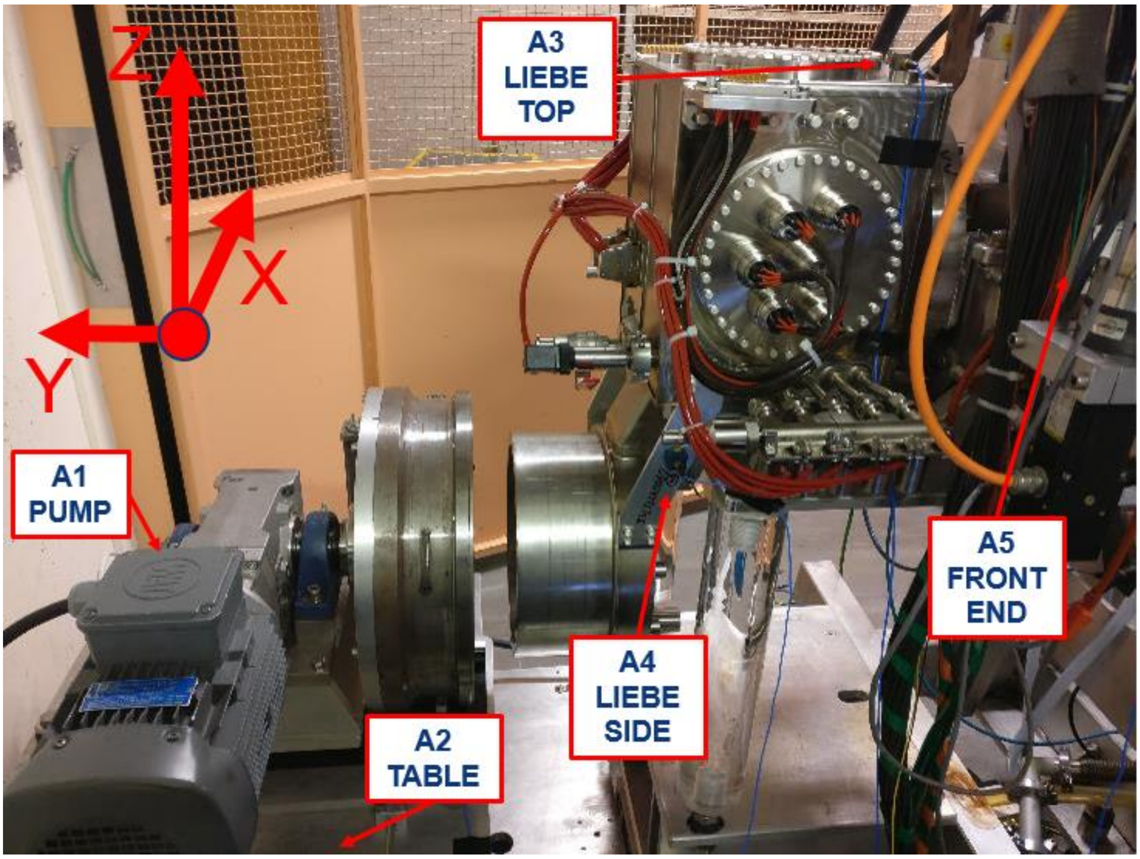


Figure 2 Measurement setup with specifed positions of all 3-axial accelerometers

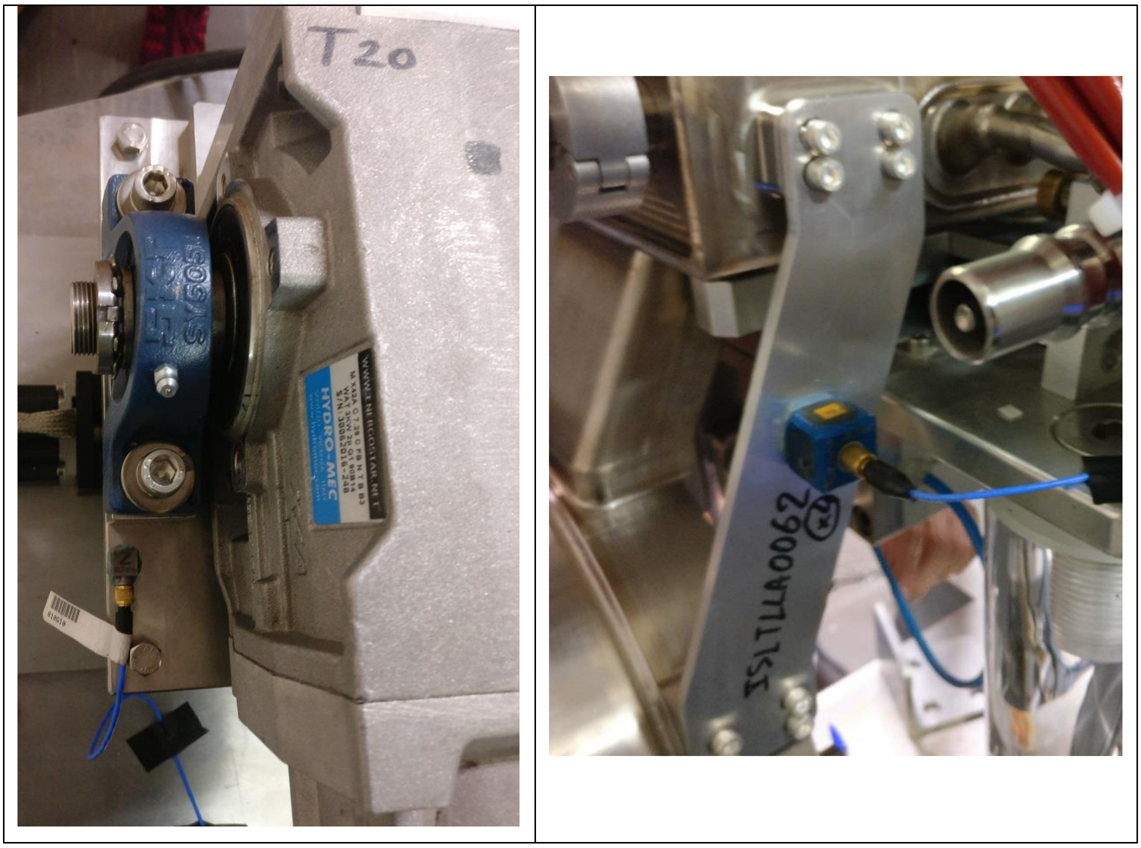


Figure 3 Position of two 3-axial accelerometers: PUMP (left), LIEBE_SIDE (right)

4. Results

Below, selected relevant results obtained from the measurements performed on the LIEBE setup are presented and described shortly. The full explanation and interpretation of this data and the impact on the setup is given in the final, summary section of this document.

4.1. Displacement PSD (LIEBE_SIDE, All Directions, 30Hz)

The following 3 figures (Figure 4Figure 6) show the calculated graphs of Displacement Power Spectral Density in LIEBE_SIDE (A4) positions for three separate directions of vibration (+X, +Y, +Z), as presented in Figure 2. For the purpose of comparison each figure contains the Displacement PSD graphs for the “Coupled 30Hz”, “Uncoupled 30Hz” and “Baseline” measurement, in the specified direction.

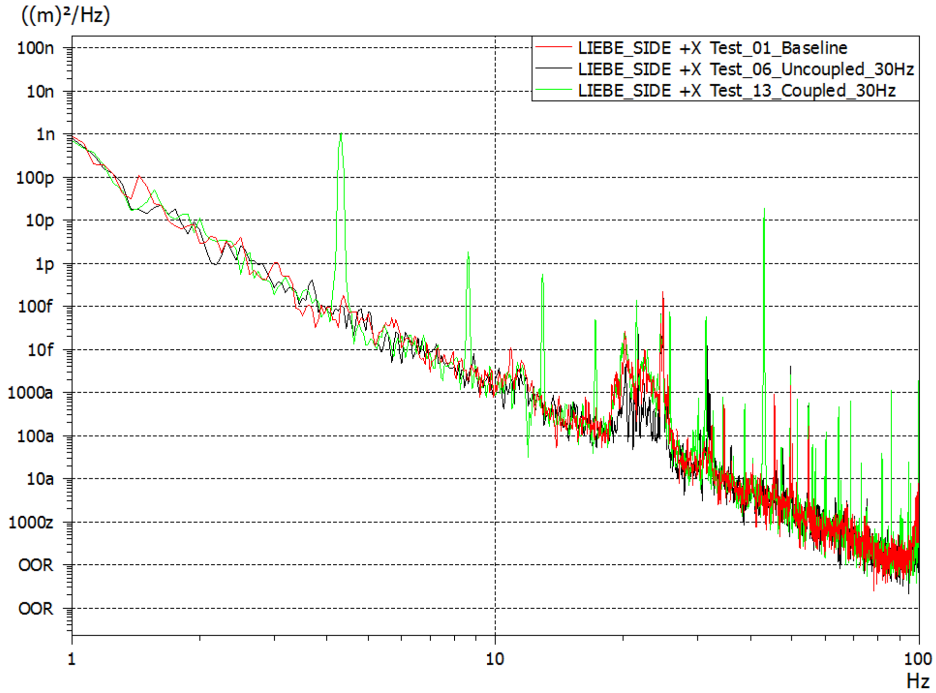


Figure 4 Displacement Power Spectral Density comparison (motor frequency 30Hz, direction +X)

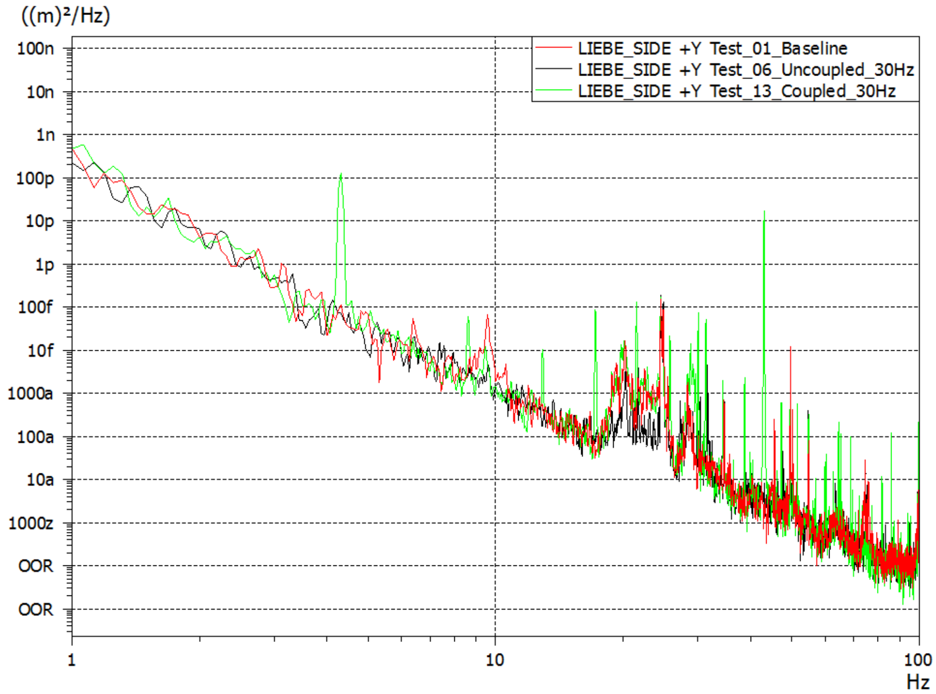


Figure 5 Displacement Power Spectral Density comparison (motor frequency 30Hz, direction +Y)

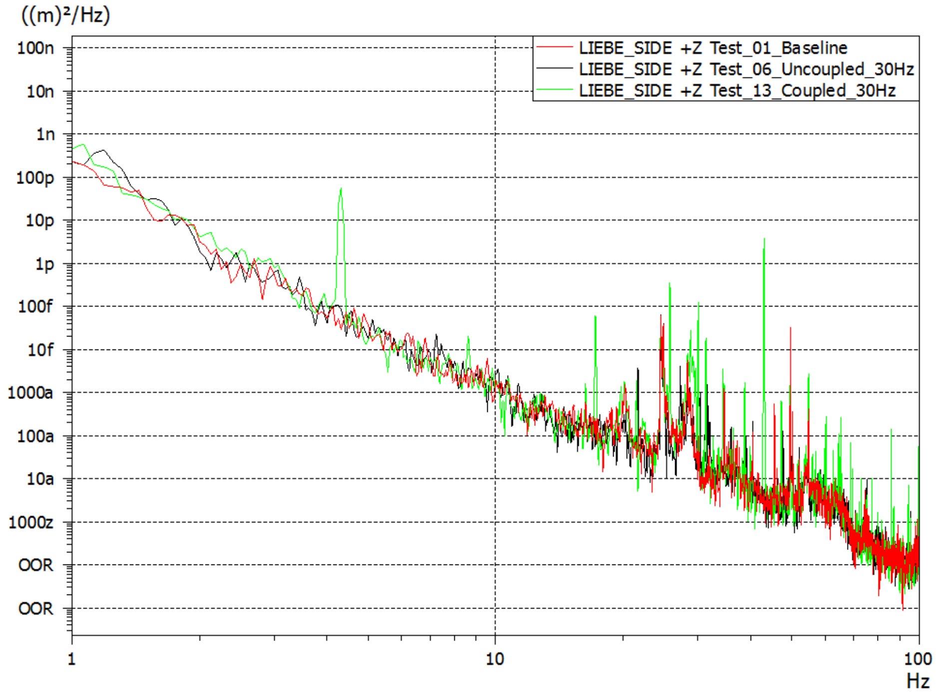


Figure 6 Displacement Power Spectral Density comparison (motor frequency 30Hz, direction +Z)

4.2. Displacement PSD (LIEBE_SIDE +Z) Comparison

The following figures (Figure 7Figure 11) show the Displacement Power Spectral Density comparison between the “coupled” and “uncoupled” tests. This comparison is done for the vertical direction of the LIEBE_SIDE (A4) accelerometer, for several values of rotational frequency, starting at 10Hz (Figure 7) and finishing at 50Hz (Figure 7Figure 11)

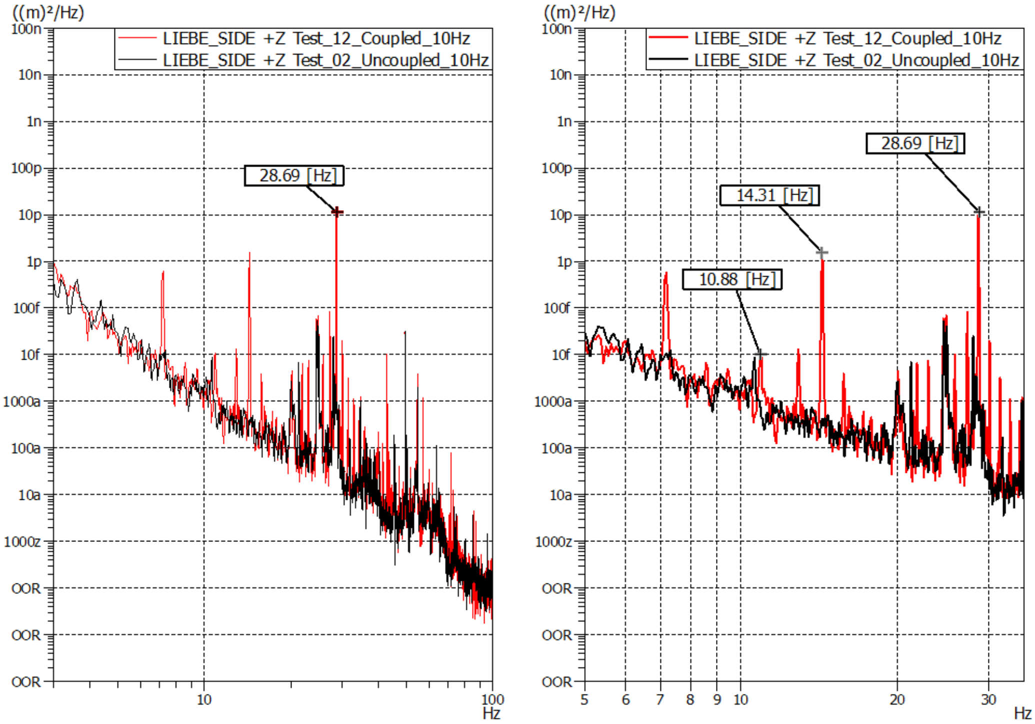


Figure 7 Displacement Power Spectral Densiry comparison
(motor frequency 10Hz, "coupled" vs "uncoupled")
[left: 3Hz – 100Hz, right: 5Hz – 35Hz]

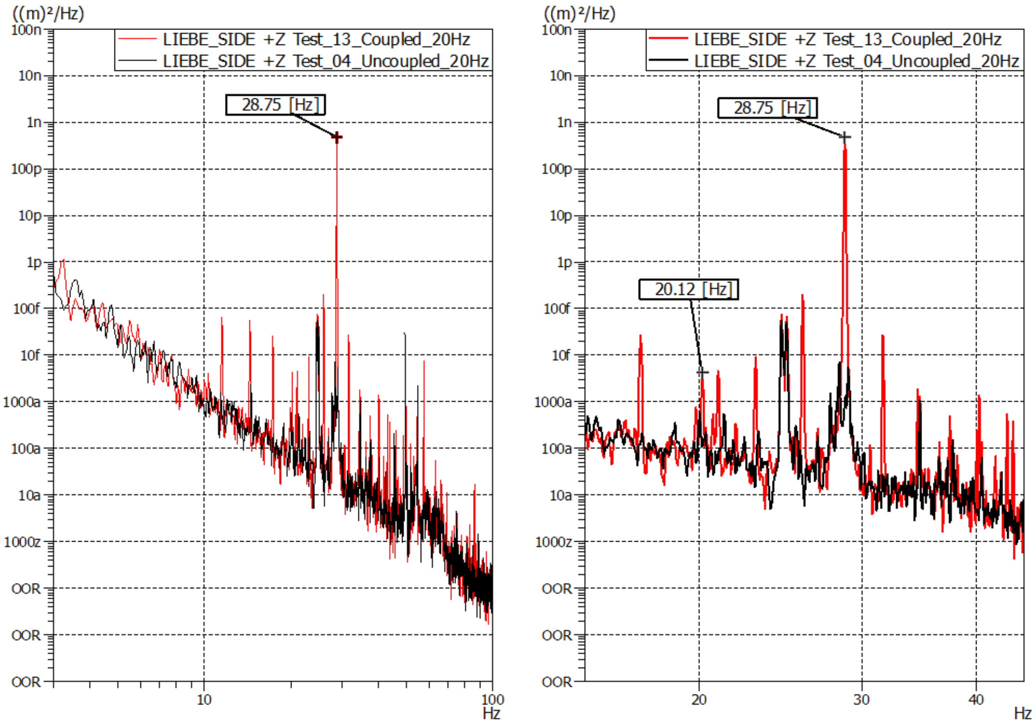


Figure 8 Displacement Power Spectral Densiry comparison
(motor frequency 20Hz, "coupled" vs "uncoupled")
[left: 3Hz – 100Hz, right: 15Hz – 45Hz]

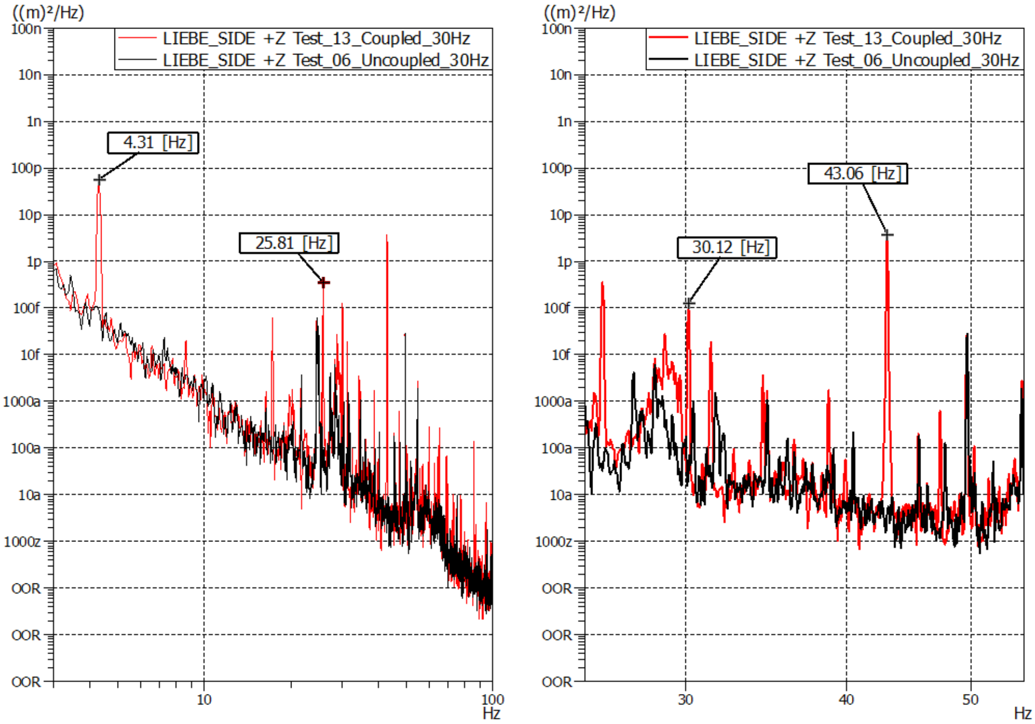


Figure 9 Displacement Power Spectral Densiry comparison (motor frequency 30Hz, “coupled” vs “uncoupled”) [left: 3Hz – 100Hz, right: 25Hz – 55Hz]

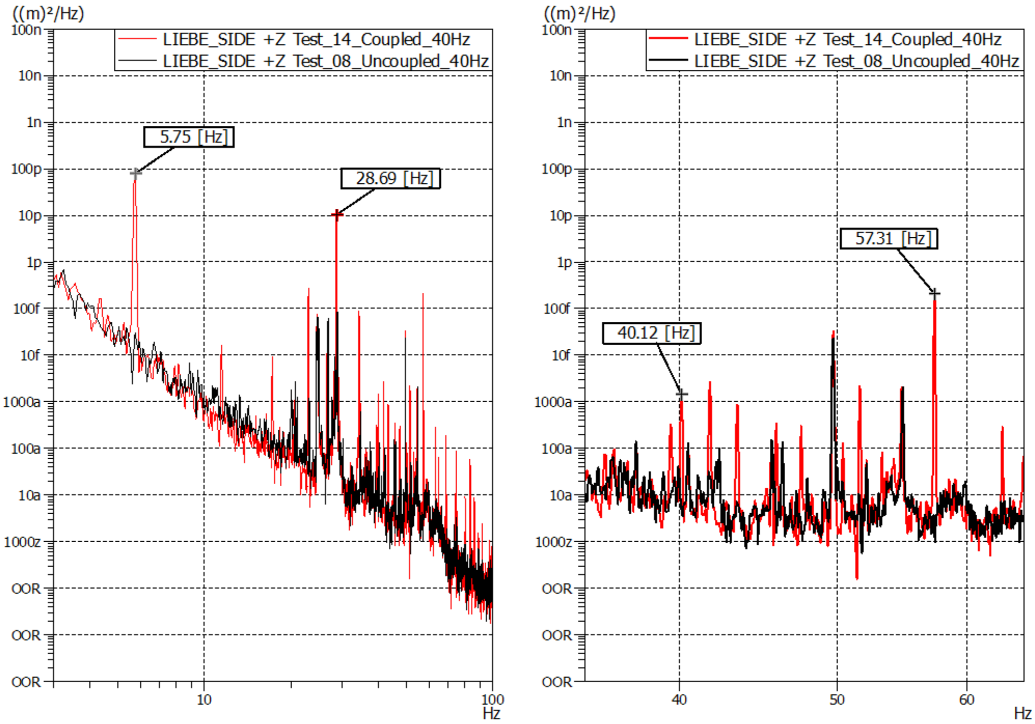


Figure 10 Displacement Power Spectral Densiry comparison (motor frequency 40Hz, “coupled” vs “uncoupled”) [left: 3Hz – 100Hz, right: 35Hz – 65Hz]

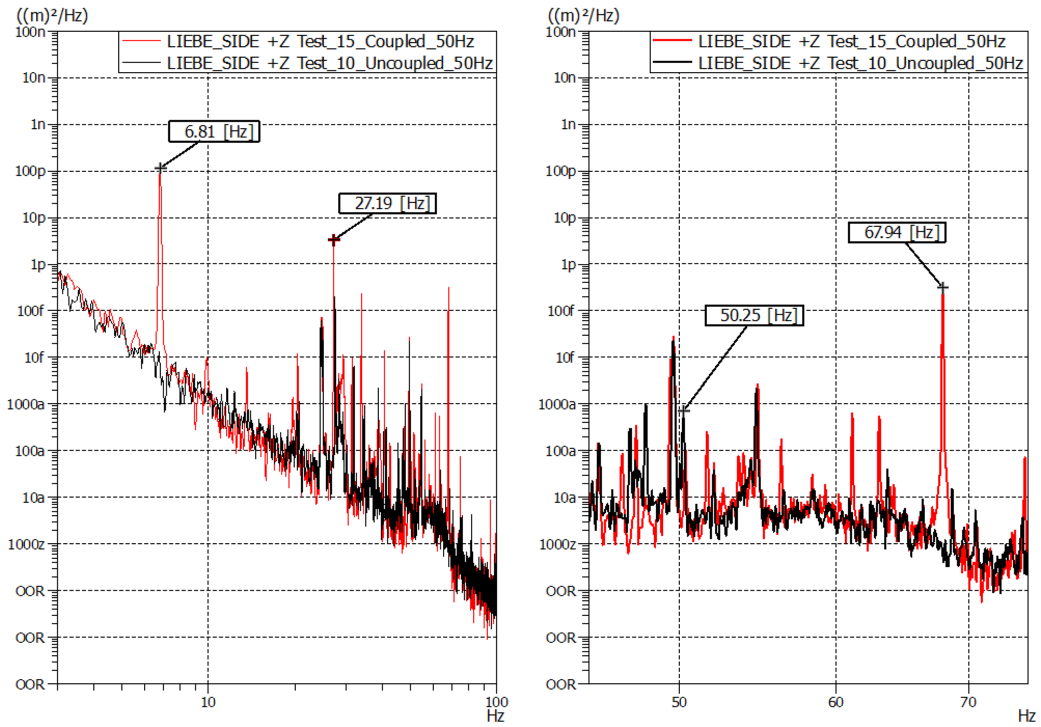
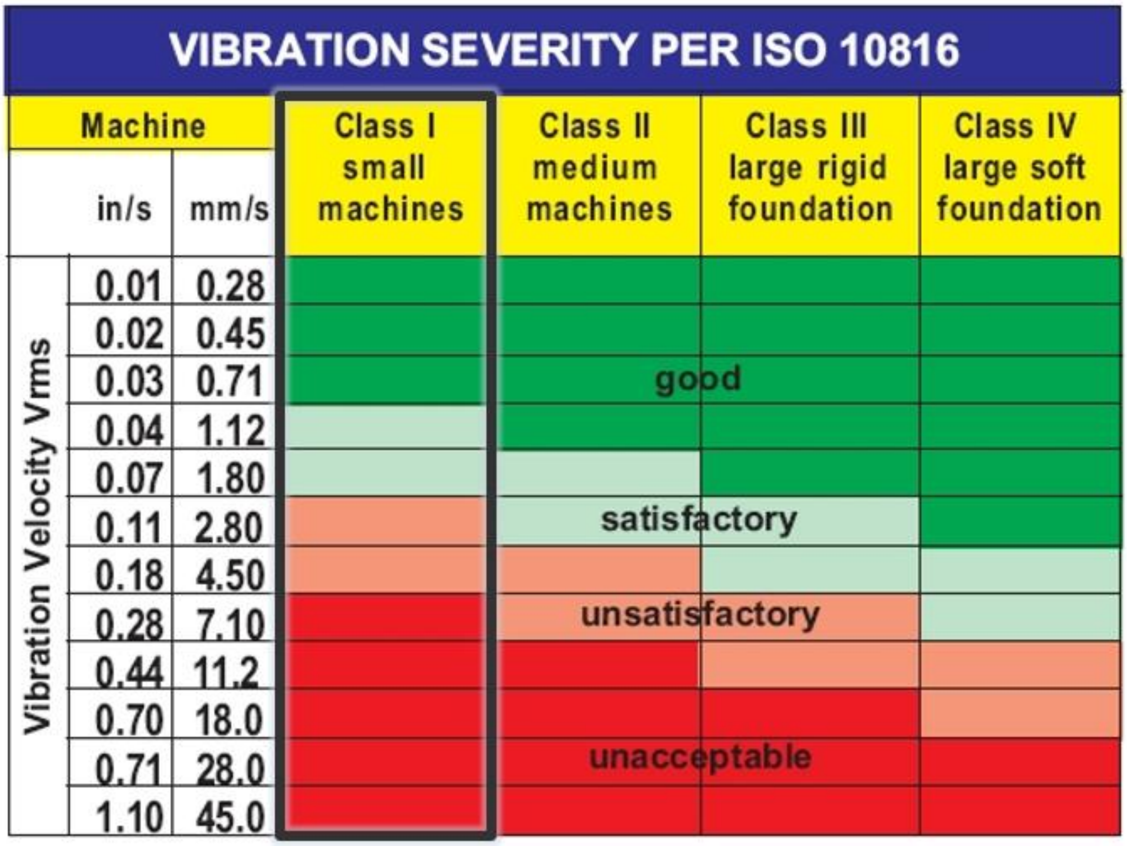


Figure 11 Displacement Power Spectral Densiry comparison (motor frequency 50Hz, "coupled" vs "uncoupled") [left: 3Hz – 100Hz, right: 45Hz – 75Hz]

4.3. Vibration severity chart

A standard way of determining the impact of vibration on the operating machine is through the vibration severity chart as shown in Table 2 and defined in detailed in ISO10816. The motor used in LIEBE experiment is considered to be in the Class I (small machines) category.

Table 2 Vibration severity chart (ISO10816) with Class I group marked (< 15kW)



VIBRATION SEVERITY PER ISO 10816					
Machine		Class I small machines	Class II medium machines	Class III large rigid foundation	Class IV large soft foundation
Vibration Velocity Vrms in/s	mm/s				
0.01	0.28	good	good	good	good
0.02	0.45	good	good	good	good
0.03	0.71	good	good	good	good
0.04	1.12	satisfactory	good	good	good
0.07	1.80	satisfactory	satisfactory	good	good
0.11	2.80	unsatisfactory	satisfactory	satisfactory	good
0.18	4.50	unsatisfactory	unsatisfactory	satisfactory	satisfactory
0.28	7.10	unacceptable	unsatisfactory	unsatisfactory	satisfactory
0.44	11.2	unacceptable	unacceptable	unsatisfactory	unsatisfactory
0.70	18.0	unacceptable	unacceptable	unacceptable	unsatisfactory
0.71	28.0	unacceptable	unacceptable	unacceptable	unacceptable
1.10	45.0	unacceptable	unacceptable	unacceptable	unacceptable

The following figures (Figure 12Figure 17) show the acceleration and velocity sum level (integrated over 1 s) for the accelerometers in PUMP and LIEBE_SIDE position, during the baseline and coupled tests (for different motor frequency operation).

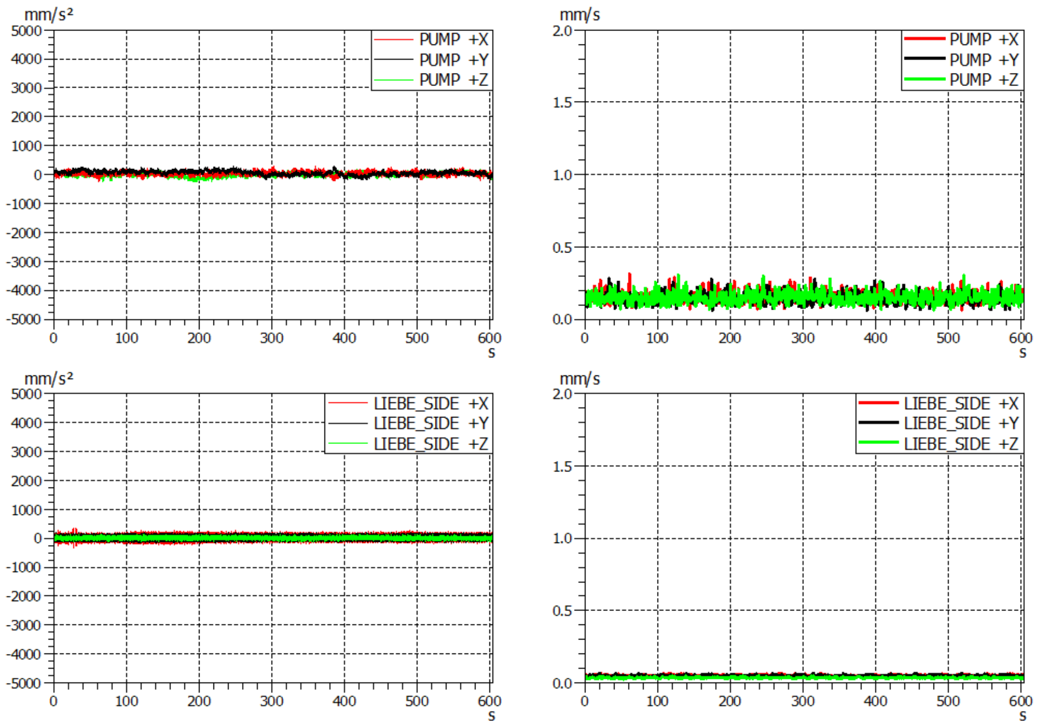


Figure 12 Acceleration (left side) and Velocity sum level [1s] (right side) for the accelerometers in PUMP and LIEBE_SIDE locations for Baseline test

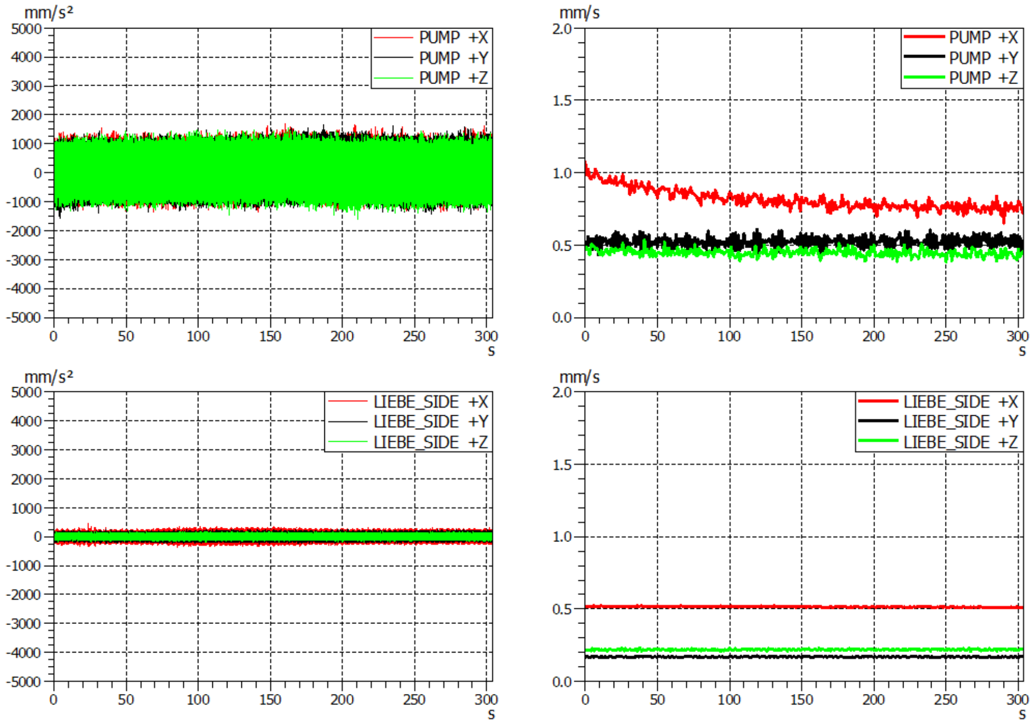


Figure 13 Acceleration (left side) and Velocity sum level [1s] (right side) for the accelerometers in PUMP and LIEBE_SIDE locations for motor frequency 10Hz

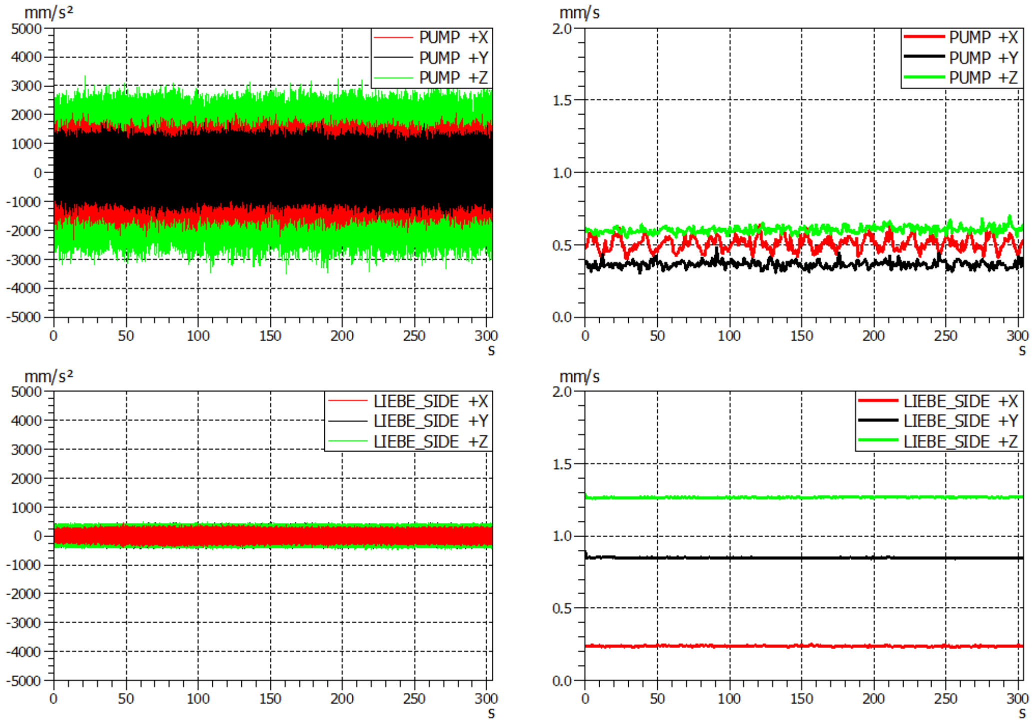


Figure 14 Acceleration (left side) and Velocity sum level [1s] (right side) for the accelerometers in PUMP and LIEBE_SIDE locations for motor frequency 20Hz

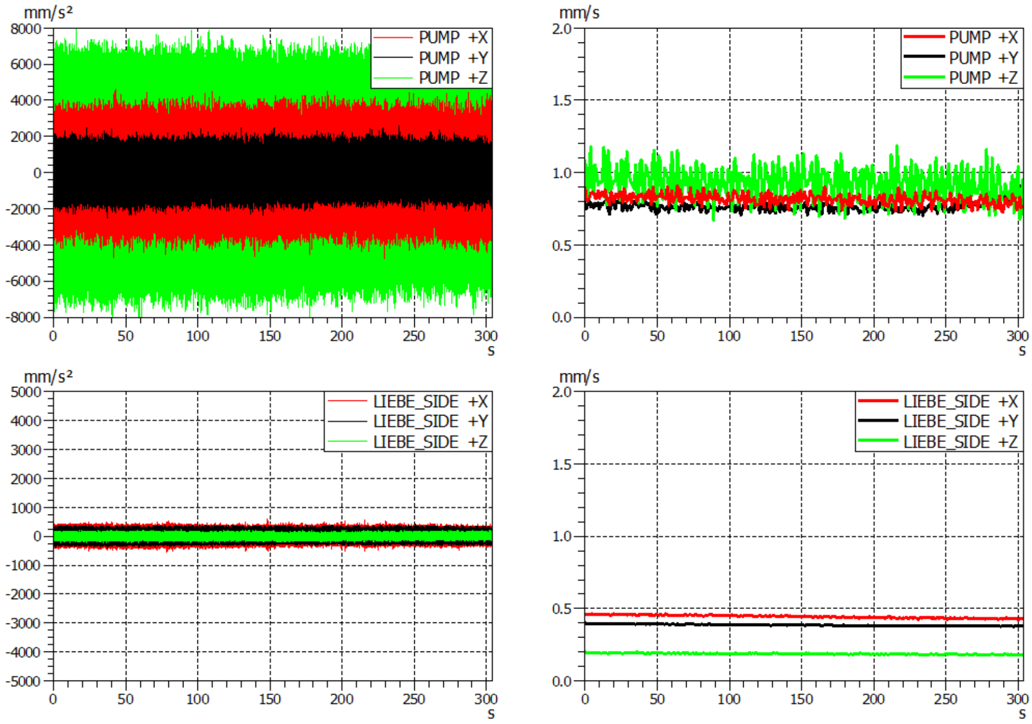


Figure 15 Acceleration (left side) and Velocity sum level [1s] (right side) for the accelerometers in PUMP and LIEBE_SIDE locations for motor frequency 30Hz

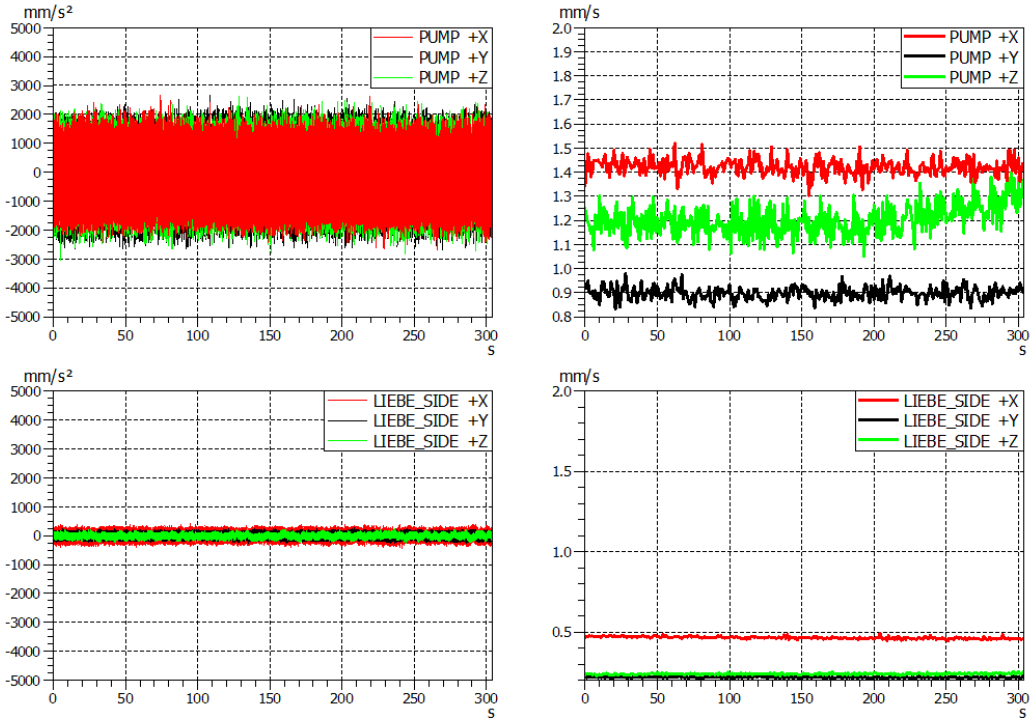


Figure 16 Acceleration (left side) and Velocity sum level [1s] (right side) for the accelerometers in PUMP and LIEBE_SIDE locations for motor frequency 40Hz

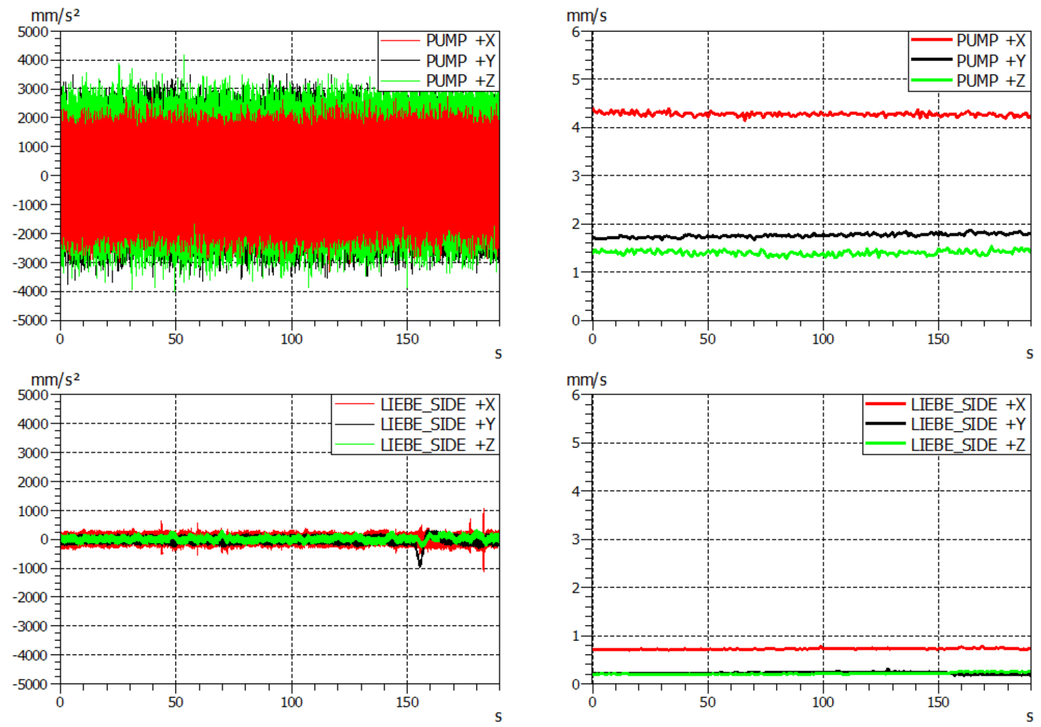


Figure 17 Acceleration (left side) and Velocity sum level [1s] (right side) for the accelerometers in PUMP and LIEBE_SIDE locations for motor frequency 50Hz

Table 3 Velocity RMS for PUMP and LIEBE_SIDE accelerometers, grouped (coloured) according to ISO10816 standard

	PUMP			LIEBE_SIDE (Uncoupled)			LIEBE_SIDE (Coupled)		
	+X	+Y	+Z	+X	+Y	+Z	+X	+Y	+Z
Baseline	0.20	0.19	0.19	0.06	0.05	0.04	0.05	0.05	0.04
10Hz	0.83	0.54	0.47	0.05	0.05	0.04	0.52	0.17	0.22
20Hz	0.54	0.39	0.64	0.06	0.05	0.04	0.24	0.85	1.27
30Hz	0.88	0.79	1.13	0.06	0.05	0.04	0.45	0.39	0.19
40Hz	1.44	0.92	1.19	0.07	0.05	0.04	0.48	0.22	0.25
50Hz	4.28	1.76	1.41	0.05	0.05	0.05	0.73	0.27	0.25

The table presented above (Table 3), has been assembled based on the calculated sum level from the measurements performed on the setup, in accordance to ISO10816, specifically the vibration severity chart (Table 2). The values have been colored according to the region of vibration severity chart they fall into (green – good, light green – satisfactory, light red – unsatisfactory).

5. Summary and conclusions.

Based on the post-processed data and the graphs presented in this report, several useful and important conclusions regarding the setup can be reached:

- The comparison of Displacement Power Spectral Density between the uncoupled and coupled operation of the setup for each motor frequency (Figure 7 Figure 11) confirms the increase in the vibration in the latter case. This is presented in the graphs in the form of additional red peaks above the black (uncoupled) level. These peaks, as expected correspond to the frequencies excited by the motor in operation. This increase in vibration is also confirmed by the increase in V_{RMS}, as given in Table 3.
- The highest frequency peaks related to the operation of the motor during the coupled measurement have been highlighted in Figure 7 Figure 11. These include the first-order motor vibration (4.31Hz, 5.75Hz, 6.81Hz in Figure 9Figure 7 Figure 11) and the actual operation rotational frequency (10Hz – 50Hz). However, it is necessary to point out that the highest peak of vibration in each case (coupled test) is present at the frequency around 1.4 times higher than the desired operation frequency (14.31Hz for 10Hz, 28.75Hz for 20Hz and so on). This informs us about an additional gear reduction present within the coupled system which causes the strong additional vibration at the fore-mentioned frequency.
- It is also important to note that for each test performed on the setup (both in the coupled and the uncoupled state) there is a large increase in vibration in the frequency range between 27 – 30 Hz. This increase can be attributed to the natural frequency present within this range. Therefore it is highly recommended not to operate the motor at the frequencies either falling within this range or causing additional vibration to be excited within the range (such as mentioned above 28.75Hz for 20Hz in Figure 8).
- Table 3 gives the estimation of the velocity of vibration on the pump and on the setup, and classifies it according to ISO10816. From this table it can be stated that is not recommended to operate the system at high frequency (up to 40 Hz is still within the limits). However, a huge increase in vibration is also visible when the frequency of operation is equal to 20 Hz. This is related to the additional frequency of 28.75 Hz falling within the range of the natural frequency of the system. Therefore, in order to avoid excessive vibration to the system, the operational frequency of the pump should lie outside the range of 9 - 11 Hz, 19 – 21.5 Hz and 27 - 30Hz.