Optimizing the Dynamic Behaviour of a Large Portal Robot

Christian R. Koenig, Markus Kochmann, Jan Ohlendorf, Dieter Müller and K.-D. Thoben

University of Bremen, Badgasteiner Str. 1, FZB - Room 2140, 28359 Bremen, Germany
chkoenig@uni-bremen.de

The object under investigation in this work is a portal robot used for the production of large fibre reinforced structures. The achieved product quality and the production speed of the device are influenced by the vibration and the damping behaviour of the system. The required process time is determined by kinematic parameters, i.e. speed and acceleration of the system and the dead time required for the vibration level to decay to a threshold level given by the required precision of process. In the first step, a Design of Experiments is used in order to identify the ideal combination of acceleration and speed. At this optimum, the sum of the drive time and the dead time reaches a minimum for a given precision. In the second step, an experimental Modal Analysis is performed in order to identify the potential for an optimization of the structure.

1 Introduction

The object under investigation in this work is a portal robot used for the production of large fibre reinforced structures. Fig. 1 e.g. is showing the Computer-Aided Design of the portal robot. In this blueprint also the effector and the feeding tray are included. Fig. 2 shows

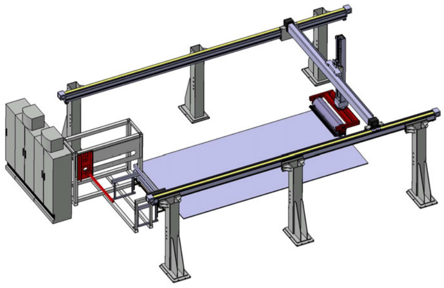

Figure 1: CAD of the portal robot

the realisation of this portal robot. The dimension of the portal robot is approx. 7m x 4m. The achieved prod-

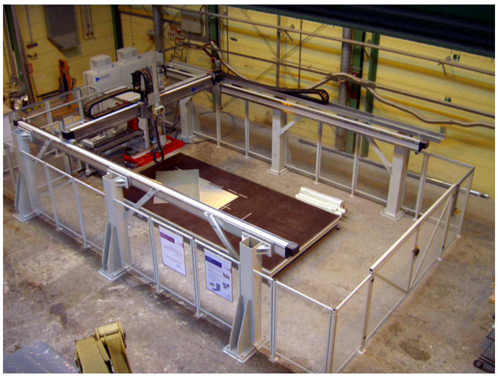

Figure 2: Realisation of the portal robot

uct quality and the production speed of the device are influenced by the vibration and the damping behaviour of the system. The required process time is determined by kinematic parameters, i.e. speed and acceleration of the system and the dead time required for the vibration level to decay to a threshold level given by the required precision of process.

2 Experiments

In the first step, the scheduled values of the machine are compared to the real achived values. Fig. 3 shows the scheduled machine parameters. The red curve shows

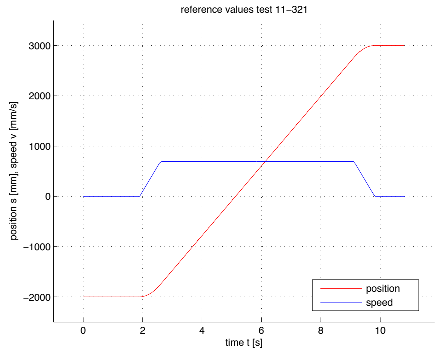

Figure 3: Scheduled values of the portal robot. The red curve shows the position of the effector in the x-direction, the blue curve represents the speed of the effector.

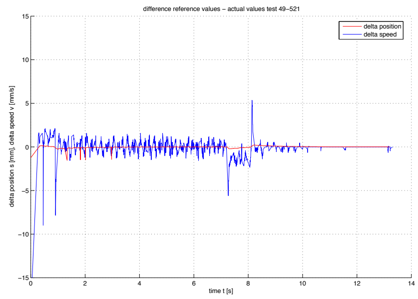

Figure 4: Difference between scheduled values and really achieved values. The red curve represents the difference in the position, the blue curve the difference in velocity

the x-position of the effector, the blue curve represents the speed of the effector. Fig. 4 shows the difference between the scheduled values and the real machine data output.

3 Results

In the next step, a Design of Experiments is used in order to identify the ideal combination of acceleration, speed and length of the z-axis (the lever of the effector). At the optimum, the sum of the drive time and the dead time reaches a minimum for a given precision of 0.5mm peek-to-peek of the oscillation ringing for this process.

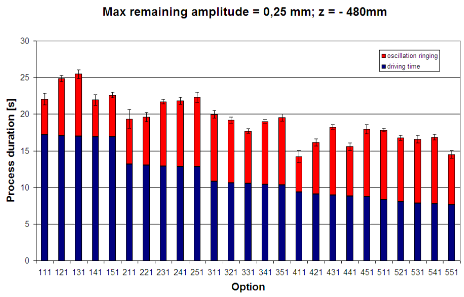

Figure 5: Process time for all accelerations and all speeds with max. lever. The blue bars represents the driving time, the orange bars are the dead times

3.1 Maximal lever, effector height $z = -480$mm

Fig. 5 shows the process time at the effector position of -480mm. This effector position means that the lever of the effector is maximal. The blue bars represents the driving time, the orange bars are equal to the dead times of the vibration level to decay to the threshold level of 0.5mm peek-to-peek. The sum is the resulting process time. Fig. 6 and Fig. 8 show the vibration level during two exemplary processes. Fig. 6 shows the process at a medium speed level of approx. $800\frac{mm}{s}$. During the phase of constant velocity the vibration levels out. A vibraton level beneath 0.5mm peek-to-peek is reached after approx. **15s** (the color of the curve is switched from blue to black to visualize the vibration level is gone below the limit of 0.5mm peek-to-peek). Fig. 7 shows the FFT of the recorded vibration level at medium speed. The eigenfrequency of the portal robot is approx. 4 Hz. The eigenfrequency is changing with diversified x-positions. Fig. 8 shows the process at a high speed level of approx. $1000\frac{mm}{s}$. During the phase of constant velocity the vibration is not leveling out. But a vibraton level beneath 0.5mm peek-to-peek is reached after approx. **13**s. Fig. 9 shows the FFT of the recorded vibration level at high spped. The eigenfrequency of the portal robot seems to be approx. 4Hz.

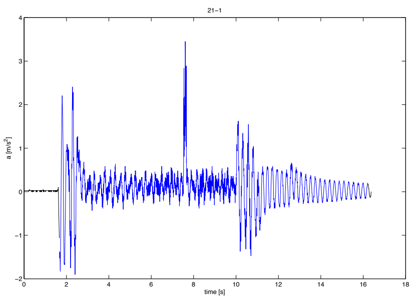

Figure 6: Exemplary vibration level at medium speed. During the phase of constant velocity the vibration levels out.

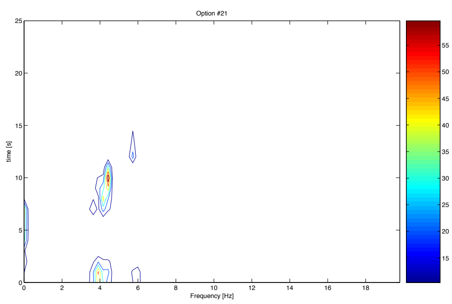

Figure 7: FFT of the recorded vibration level at medium speed. The eigenfrequency of the portal robot is approx. 4Hz

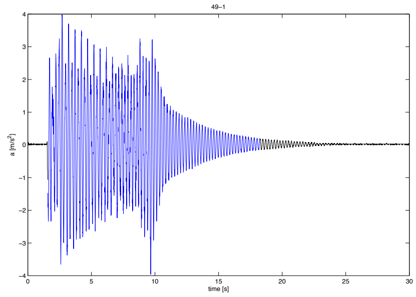

Figure 8: Exemplary vibration level at high speed. During the phase of constant velocity the vibration is not leveling out.

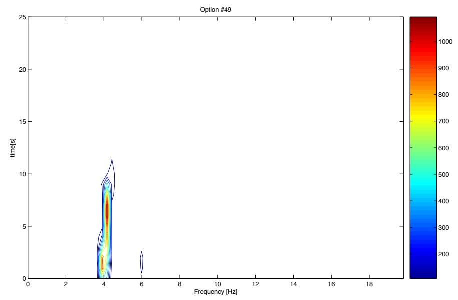

Figure 9: FFT of the recorded vibration level at high spped. The eigenfrequency of the portal robot is approx. 4Hz

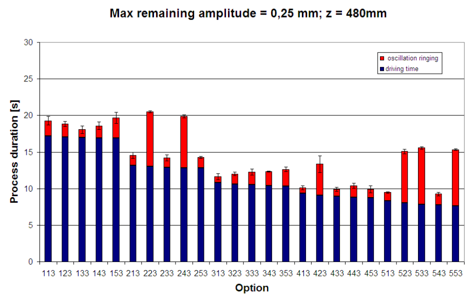

Figure 10: Process time for all accelerations and all speeds with minimal lever. The blue bars represents the driving time, the orange bars are the dead times

3.2 Minimal lever, effector height $z = +480$mm

Fig. 10 shows the process time for the effector position of +480mm. This means that the lever of the effector

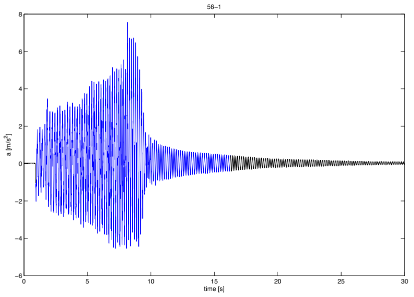

Figure 11: Exemplary vibration level at high speed. During the phase of constant velocity the vibration is not leveling out.

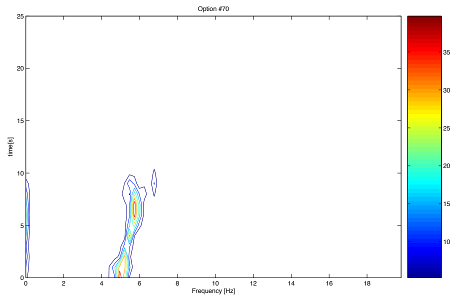

Figure 14: FFT of the recorded vibration level at medium spped. The eigenfrequency of the portal robot is approx. 5Hz

is minimal. It is easy to see, that the dead time for the

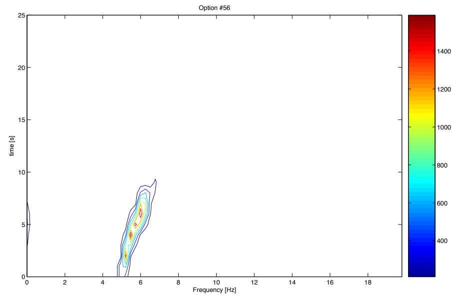

Figure 12: FFT of the recorded vibration level at high spped. The eigenfrequency of the portal robot is approx. 5Hz

vibration level to decay to the threshold level of 0.5mm peek-to-peek is much lower at minimal lever. The blue bars represents again the driving time, the orange bars once again the dead times caused by the decay of the vibration. The sum of both is again the resulting process time. Fig. 11 and Fig. 13 show - analog to the ivestiga-

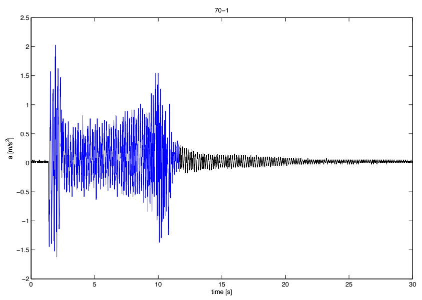

Figure 13: Exemplary vibration level at medium speed. During the phase of constant velocity the vibration is leveling out.

tion with the maximal lever -, the vibration level during two processes with same velocity and acceleration as in the first part of the investigation. So Fig. 11 shows the process at the high speed level of approx. $1000\frac{mm}{s}$. During the phase of constant velocity the vibration is again not leveling out. A vibraton level beneath 0.5mm peek-to-peek is reached after approx **14**s. Fig. 12 shows the FFT of the recorded vibration level at high speed. The eigenfrequency of the portal robot has changed to approx. 5Hz. This time the second Figure - Fig. 13 - shows the process at the medium speed level. Also during the phase of constant velocity the vibration levels out. A vibraton level beneath 0.5mm peek-to-peek is reached already after **10**s. Fig. 14 shows the FFT of the recorded vibration level at medium speed. The eigenfrequency of the portal robot has changed to approx. 5Hz.

4 Modal Analysis

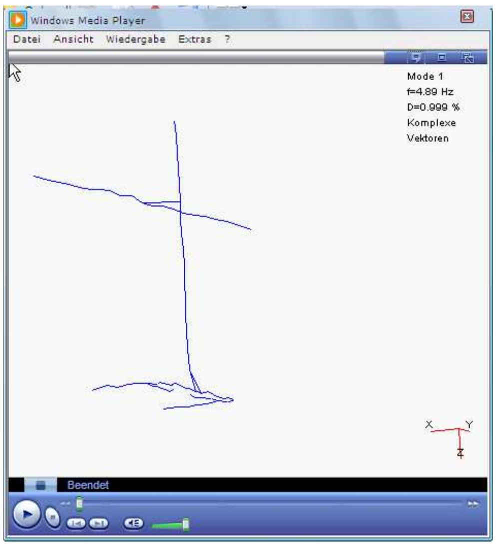

Figure 15: Result of the experimental Modal Analysis

4.1 Experimental Modal Analysis

In the second step, an experimental Modal Analysis is performed in order to identify the potential for an optimization of the structure. Fig. 15 shows the result of the experimental modal analysis. The first eigenfrequency of the system is recognized at 4.89 Hz with a damping ratio of 0.99%.

4.2 Finite Element Method

After the experimental investigations a finite element model was developped to describe the dynamic behaviour

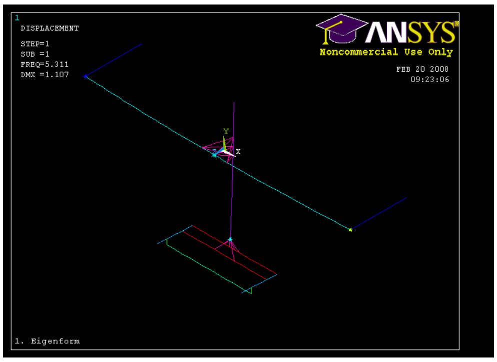

Figure 16: Finite element simulation of the dynamic behaviour of the portal robot

of the portal robot. Fig. 16 shows the result of a Finitie Element Simulation of the portal robot. In this model

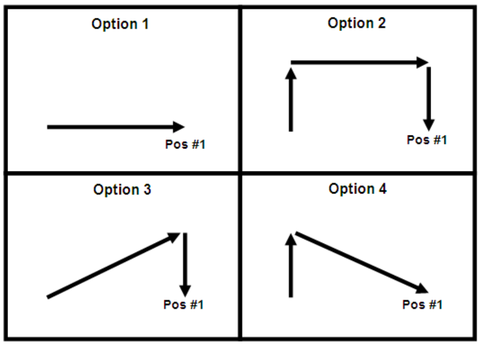

Figure 17: Schematic view of some possible different driving tracks

the first eigenfrequency of the system is determined at 5.31Hz with a damping ratio of 1.11%.

5 Evaluation of different driving tracks

Due to the results of the experimental analysis further inevstigations are carried out. The process has to begin and end at the maximal lever position (Pos# 1). There exsist several diffent possible ways to move the effector from its endposition to Pos# 1 are possible. Fig. 17 shows these options. The effector can be moved directly

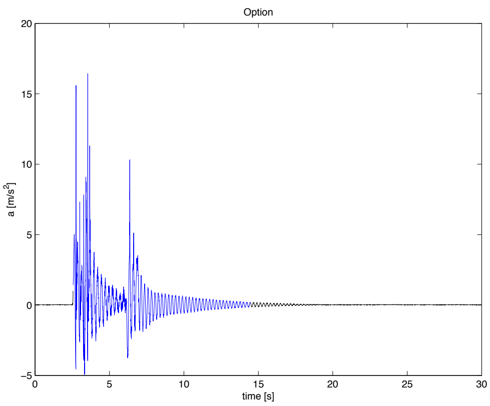

Figure 18: Driving track - Option 1

from the endposition to Pos# 1 (1). Another possibility is to first lift up the effector than move it translational and finaly lift the effector down to Pos# 1 (2). Also the effector can be lifted up or down diagonal (3) and (4). Fig. 18 - Fig. 21 show the result of the different moving

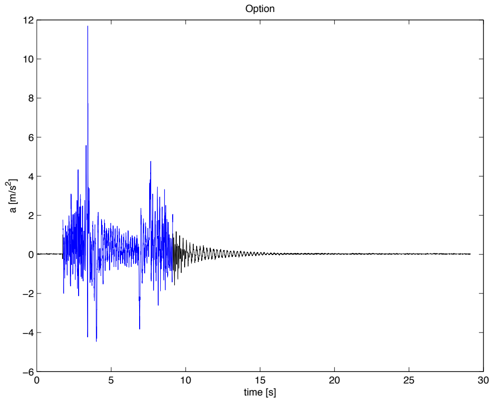

Figure 19: Driving track - Option 2

options at maximum speed and maximum acceleration of the portal robot. At least, Option 1 takes about **12**s,

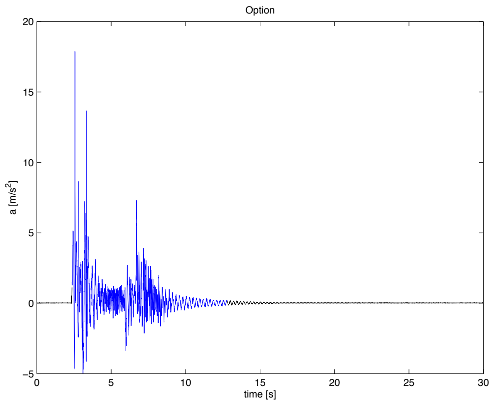

Figure 20: Driving track - Option 3

Option 2 needs approx. about **7**s, Option 3 approx. about **10**s and Option 4 approx. about **14**s. Option2

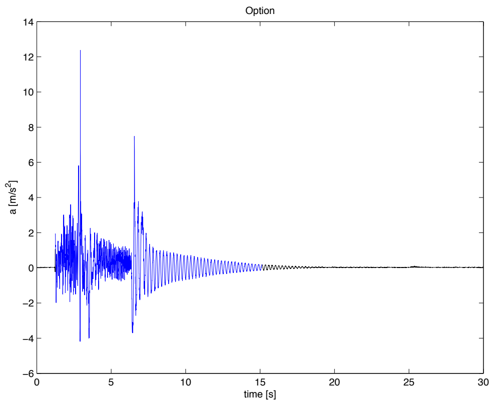

Figure 21: Driving track - Option 4

seems to be the best driving way to achieve minimal process times.

6 Conclusion

Experimental investigations concerning the dependance of process time and process parameters have been carried out. An increasing lever size leeds to an increasing time for vibration to level out. An experimental modal analysis has been performed and the portal robot was implemeted as a finite element model. This model can be used for virtual prototyping to evaluate the possible changes in the dynamic behaviour of the portal robot if the boundary conditions are changing. Finally an optimized driving way has been found to minimize the process time.

References

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[2] Experimentelle und rechnerische Modalanalyse sowie Identifikation dynamischer Systeme. Tagung Kassel, Juni 2000