Towards the Practical Application of Dynamic Error Budgetting

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Abstract

In accurate mechatronic applications the feedback control will make sure that static position errors, as measured by the system sensors, will be equal to zero in the undisturbed state. During normal operation however systems will be subjected to many different disturbances. The power of the controller to counteract the effects from such disturbances is generally limited and thus accuracy, as measured at the system sensors, is limited.

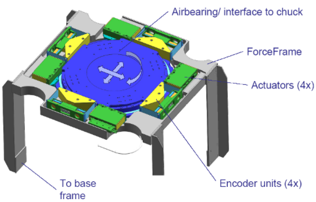
During the design of new systems it is required to be able to predict the performance. To be able to give such predictions, models of the system behaviour are generally made. Such models, when properly used, allow to design suitable control schemes. In many cases the design will be optimized to achieve a certain dynamic response or a certain error correction capability as a function of frequency. For the customer, it is however required to predict the position errors as a function of time under the influence of all potential disturbance sources.

The "Dynamic Error Budgeting" as introduced by Jan van Eijk et al. in 2004 is an approach which builds upon the use of Parseval's theorem linking frequency domain and time domain data. In this method the different disturbance sources are identified during design. Suitable estimates of the magnitude and frequency content are determined or measured and used to act upon the model of the controlled system. The frequency domain transfer functions of each disturbance to the performance parameter of the design are used to calculate the Power Spectral Density of the performance. Based upon this information the total performance in time domain, statistically expressed, can be calculated. The individual contributions can be

identified and the dominant dynamic effects can easily be seen in the "Cumulated PS" over the relevant frequency domain.

In this paper we applied the method to a 20 nm accurate XY-Rz stage both for design and for verification. Disturbances taken into account are: floor vibrations, amplifier noise, quantisation of position measurement and quantisation due to A/D conversion in the current loop. From model and disturbance verification we derive practical rules for application. Matlab/Simulink tools have been developed for ease of use. The Dynamic Error budgeting will be compared with full modelling in time domain both for verification and practical use.

Special attention is given to amplifiers with pulse width modulation (PWM). In nanometer application they are sometimes avoided due to the noise. Although the audio noise can be heard, it is shown that the contribution to the position error in these applications is less than expected. Measurements will be shown as well.



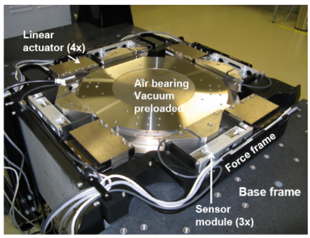


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Figure 1 Drive and control concept using air bearings, linear motors, linear encoders and a force frame

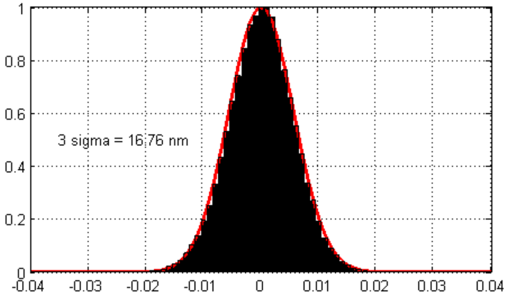

Figure 2. Repeatability error distribution for 1350 small moves, 3σ value = 16.76 nanometer (measurement error of 1 nanometer included)

We conclude that DEB gives good estimates of the expected performance in an early stage of the design. To achieve better estimations time domain simulations are needed. Because this requires more knowledge of the system it can be used in a later stage of the design.

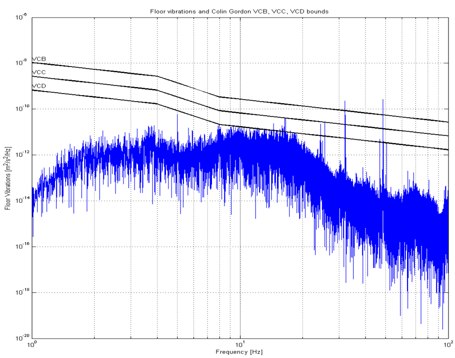

Figure 3. Disturbances from floor vibrations measured by geophones as a function of frequency. Floor is at VC-C specification if we neglect peaks at 48 and 32 Hz due to one single disturbance source.

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