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An Adams/View-Matlab Computational Interface for Clustered Optimization of Washing Machines

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Summary This paper describes an Adams/View-Matlab environment for parallel/clustered calculations running on ordinary workstations. The system was developed for sensitivity analysis and bi-objective optimization of washing machine performance by using a dynamic model built in the commercial multi-body software MSC.Software Adams\View. Together with statistics of performance of the system, results of a bi-objective optimization of a selection of structural parameters are presented.

Keywords: Bi-objective optimization, parallel computing, washing machine dynamics, vibration control

Introduction

Optimization of dynamical systems is often computationally demanding. Not seldom days or weeks of computational time have to be spent on solving an optimization problem. Several things influence on the CPU-time it takes to solve a specific problem. Always important are the number of parameters to be optimized and the complexity of the model which directly affect the time it takes to solve its equations. The number of conditions for which the model must be evaluated has also a strong influence on CPU-time. For instance, in the case of optimization of a car suspension it could be different road types or handling situations that the suspension needs to perform in. The amount of time it takes to prepare a model for simulation has also an effect on the time consumption. Sometimes heavy in data is needed to be loaded from disk before running.

The paper aims to present a developed computational environment for clustered bi-objective optimization of washing machine dynamics on a set of its operational conditions.

The washing machine model

A washing machine is an object familiar to almost everyone. Many people associate washing machines with noise and vibration, and locate their machine to remote parts of their house or apartment. With extreme cases of unbalanced load, which is the main reason to vibrations and noise, together with a fail of the unbalance detection electronics a washing machine behaviour called “walking” can occur. Walking happens when the normal forces of the floor become too low in relation to the lateral forces and the foot loses its grip.

To deal with these and other issues related to vibration analysis, control and dynamics optimization, a model of a modern in-production washing machine has been developed. Work has been performed during the last couple of years in collaboration with the washing machine manufacturer Asko Appliances AB [1, 2].

The work has resulted in a rigid multi-body model which has been implemented in the commercial software Adams/View. It can be seen together with relevant inner structural components of a physical machine in figure 1. Model parts are constructed using CAD drawings giving accurate inertia properties and joined with appropriate constraints. Remaining structural components of importance have been measured separately with dynamic measurement test-rigs resulting in separate sub models for dampers, springs, rubber bushings and feet. Details on the sub models can be found in [1, 2].

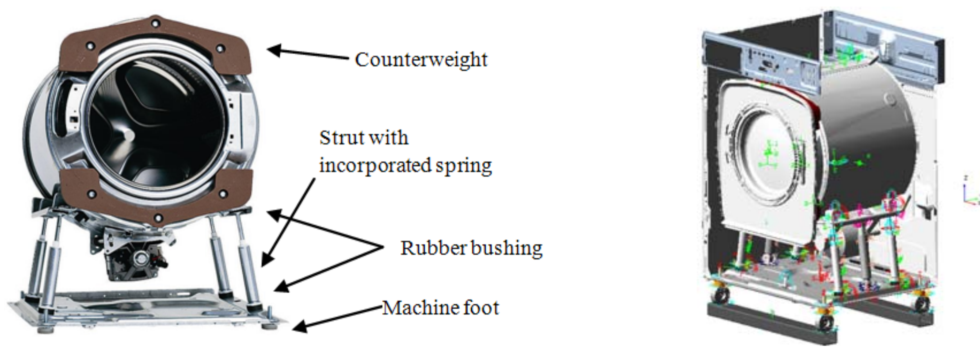

Figure 1: Some of the inner parts of a washing machine and the Adams\View model representation.

The optimization problem

In this paper two criteria of high importance in washing machine dynamics will be used. The first is to keep the tub free from hitting the housing during washing. The second is to limit the propagation of forces through the structure to minimize vibration impact on surroundings and to prevent the machine's walking behaviour [2]. The first objective to be minimized is defined as follows:

$$\Im_K = \max_p \left(\max_t \left(\Delta \mathbf{X}_p(t) - \Delta \mathbf{X}_p^{\max} \right) \right), \, p = 1,2,3...9, \forall t \in [0,T] \quad (1)$$

where $\Delta \mathbf{X}_p$ and $\Delta \mathbf{X}_p^{\max}$ are movement and movement margins in three directions at the points p of the tub which have been defined as critical by the manufacturer. The second objective to be minimized is the sum of the RMS-values of the vertical forces F_i^z, (i=1,2,3,4) at the four feet of the machine during the simulation time T and is written as

$$\Im_D = \sum_{i=1}^{4} \sqrt{\frac{1}{T} \int_0^T \left(F_i^z(t) \right)^2 dt} \quad (2)$$

To be a feasible product to sell, a washing machine has to be able to handle different amounts of load and different imbalances. To reflect these different operational conditions three critical load cases with respective drum rotational excitation schemes are defined as follows:

1. Constant load of 1kg placed in the front of the drum whilst spinning up to 800rpm with a gradient of 80rpm/s.
2. Constant load of 0.3kg placed in the middle of the drum whilst spinning up to maximum spin speed.
3. Maximal load of the machine distributed evenly in the drum with an exception of 1 kg, which is placed in the front of the machine.

The bi-objective optimization problem of washing machine vibration dynamics on a given set of operational conditions is stated as follows.

Problem A. It's required to determine the vector of structural parameters $\boldsymbol{\xi}_*$ and state vector $\mathbf{x}_*(t)$ which satisfy the variational equation $\min_{\xi, \mathbf{x}(t)} \left\{ \mathbf{F}\left[\boldsymbol{\xi}, \mathbf{P}, \mathbf{x}(t) \right] \right\} = \mathbf{F}\left[\boldsymbol{\xi}_*, \mathbf{P}, \mathbf{x}_*(t) \right]$ subject to the differential equations of motion $\dot{\mathbf{x}} = \mathbf{f}\left(\mathbf{x}, t, \boldsymbol{\xi}, \mathbf{P} \right)$ and constraints $\mathbf{B}_l \le \boldsymbol{\xi} \le \mathbf{B}_u$. Here $\mathbf{F} = \left[\Im_K, \Im_D \right]^T$, $\mathbf{P} = \left[\mathbf{P}_1, \mathbf{P}_2, \mathbf{P}_3 \right]^T$ where $\mathbf{P}_i$ is a vector of input parameters to the operational condition i, *(i=1,2,3).*

The computational environment and optimization results

To solve Problem A a computational environment has been created. It consists of one computer equipped with Matlab running an optimization algorithm. To this computer an arbitrary amount of computational processes, on the same or on other computers, running Adams/View can be connected through a developed interface.

The dynamical system model opened in Adams\View contains a macro which when it runs creates a unique ID for the program instance and registers it on a network path. It then loops waiting for commands or simulation in data. The in data for the simulations are created in Matlab by the optimizing algorithm and written to files by the developed interface which marks them with the ID of an available node. The interface enables parallel start of simulations if the optimizing algorithm can take advantage of this. One optimizer which works in parallel is the used MATLAB function '*gamultiobj'* from the 'Genetic Algorithm and Direct Search'. This optimizer creates a set of in data (called generation) at each optimization step and makes it available for the interface function to start. The interface searches for available computers to start simulations on, searches for and processes calculated files, sends status messages to the user and restarts crashed simulations when the Adams/View program or a computer is the reason for the crash.

As an example of a solution of Problem A the following results are presented. The resulting Pareto front visible on the left of figure 2 was obtained by the optimization algorithm after more than 3500 evaluations of sets of parameters ξ.

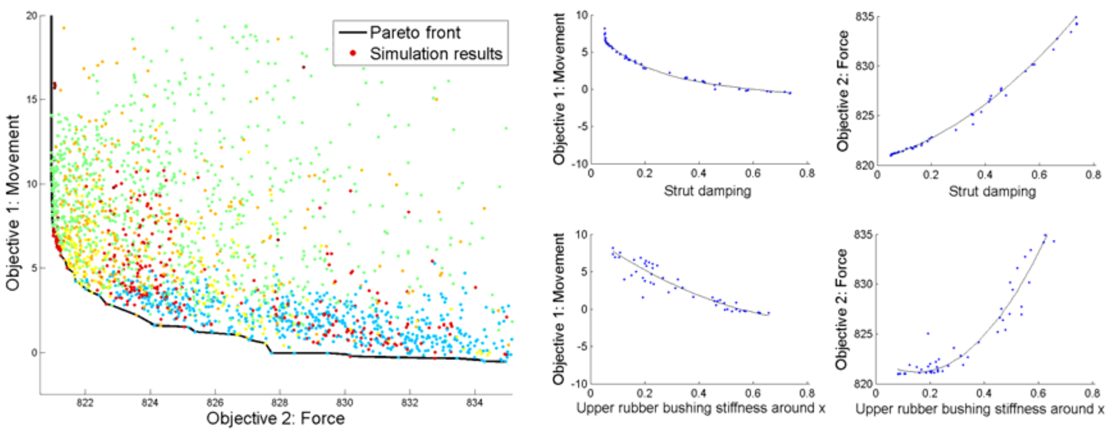

Figure 2: Resulting Pareto front from optimization together with a selection of resulting parameter values.

Together with the Pareto front some of the simulations are plotted with color depending on which of the points *p* where active in equation (1), i.e. at which point the maximum movement in relation to the allowed occurred. On the right side of figure 2 two of the variables which values results in optimal performance are plotted against the respective objective. The conflicting nature of the two objectives can clearly be observed.

Cluster performance

As a performance test a special simulation case (not connected to Problem A) was created. Here all parameters were held constant during simulation to enable predictable calculation time. Varying the time of simulation *T*, resulted in the relation for the cluster efficiency showed in figure 3 peaking at 96% for a *T*=251 s simulation. The data of each point is based on an average of 100 simulations. A curve is fitted to the points following the function *g(t)* in equation (3)

$$g(t) = 100 \times \left(1 - \frac{a}{t+b} - ct\right) \tag{3}$$

where a=5.45, and b=5.44 and c=0.00101 giving a goodness value R^2=0.997.

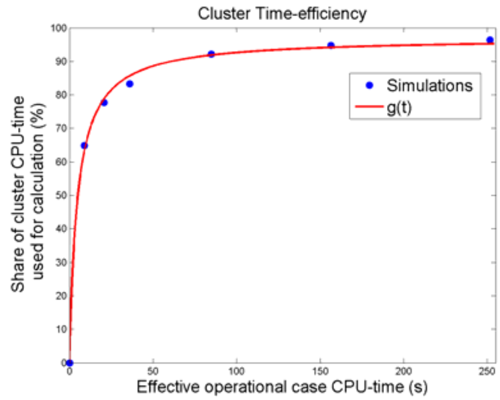

Figure 3: Efficiency of the cluster as a function of effective simulation time.

So, it can be stated that the average constant delay for results file administration for each simulation can be estimated to 5.44 seconds. The administration includes file reading and writing in Adams/View and input file-generation in Matlab. Included in this is a random delay which can be anything between 0 and 4 seconds depending on when for example Adams searches for files in relation to when it is written by Matlab. The random delay can be tuned further if found necessary. A file reading and writing time depending on the size of the output file is reasonable and represented here by coefficient c.

Concluding remarks

An Adams/View-Matlab based interface has been developed for parallelized computation and constrained multi-criteria optimization of washing machine dynamics on a set of critical operational conditions.

Implementation of the developed tools on ordinary workstations has proved calculation efficiency of up to 96% in case of optimization of the dynamics of a modern washing machine.

By using the developed interface and tools a Pareto front has been found giving the domain of realistic structural parameters with optimal dynamic and kinematic performance.

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