

Parametric Studies in Product Development using SKF BEAST on Multi-Processor Platforms



MODPROD 2010, Linköping, Sweden Dag Fritzson, SKF ERC 2010-02-10



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Outline of presentations

BEAST?

SKF Product Development Process and Simulation

Example of using Design For Six Sigma (DFSS) tools (quality, parameter studies, and statistics)

Parallel Computation

Summary

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BEAring Simulation Tool

-The devil is in the details





BEAST - a virtual test rig

- Multi-body simulation software
- Specialized in contact problems
- Detailed surface description
- Accurate tribology
- Application operating conditions
- Focus on creating understanding of systems with contacts
- BEAST was originally developed for rolling bearings, but can be used for any "contacting" machine element





The Product Development Process and Simulation



Product Development Process (PDP)



PDP and Design for Six Sigma (DfSS) integrated







The EASY work process



The EASY work process – Concept studies **Requirements** Automatic data Translation reduction from Load case date bases 4D/3D to scalar Performance criteria A few selected load cases Automatic simulation of values **BSL** criteria selected load cases with one command Comprehensive presentation **Reduced** or full model Tables or diagrams, load case versus criteria A few main design parameters (e.g., geometry, tolerances, surface properties, material, etc) Sensitivity/robustness analysis Improve/optimize Automatic translation product Multi-criteria optimization (DoE or "automatic") Manufacturing process parameters 2010-02-10 ©SKF Slide 10 [Code] SKF [Organisation]

The EASY work process – Detailed design **Requirements** Automatic data Translation reduction from Load case date bases 4D/3D to scalar Performance criteria **Selected load cases** Automatic simulation of values **BSL** criteria selected load cases with one command Comprehensive presentation Reduced or full model Tables or diagrams, load case versus criteria All relevant design parameters (e.g., geometry, tolerances, surface properties, material, etc) Sensitivity/robustness analysis Improve/optimize Automatic translation product Multi-criteria optimization (DoE or "automatic") Manufacturing process parameters 2010-02-10 ©SKF Slide 11 [Code] SKF [Organisation]

The EASY work process - Verification



Examples of tools that can be used

Minitab statistical software (www.mintab.com) is a standard SKF DfSS and Six Sigma tool it covers statistics, DoE, optimization, etc. **DoEBeast/Beauty** it is small but focused on DfSS usage, i.e., parametric studies (DoE), sensitivity/robustness analysis it has import/export to minitab it has optimal connection/usage of BEAST modeFRONTIER (www.esteco.com) is a general tool focused on optimization HyperStudy (www.altairhyperworks.com) is a general tool





The DFSS supports use of simulation.

There is an expressed intention in SKF to use modelling and simulation early in the PDP, and to larger extent.



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Examples of a Parametric Study

Examples of a Parametric Study using DFSS tool



Setting up a screening design

A BEAST model is turned into a parameter study by adding a *parameter_study* node (right click environment):

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Screening...(cont.)

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Screening...(cont.)

	Parameter name	User variable name	In category	Reference value	StdDeviation	
	IRcurv	IRcurv	model	50*um		
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	RalR	RalR	model	0.09*um		
	RaRE	RaRE	model	0.048*um		
	FilmThick	FilmThick	model	0.1*um		
	RaCage	RaCage	model	0.2*um		
	RaGR	RaGR	model	0.2*um		
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Choose fractional factorial and enter the lower and upper limits of your parameters #simulations = 2^(parameters - #generators):

	Parameter name	User variable name	In category	Parameter levels	Reference value	StdDeviation	\square	
	IRcurv	IRcurv	model	[-50*um,50*um]	50*um		1	
	REcurv	REcurv	model	[-300*um,-200*um	-250*um			
	RaiR	RaiR	model	[0.01*um,0.2*um]	0.09*um			
	RaRE	RaRE	model	[0.02*um,0.05*um	0.048*um		1	
	FilmThick	FilmThick	model	[0.1*um,0.4*um]	0.1*um			
	RaCage	RaCage	model	[0.1*um,0.3*um]	0.2*um		1	
	RaGR	RaGR	model	[0.1*um,0.3*um]	0.2*um		-	
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Choose Chart of Effects from menu. We decide to look at E_slip_perf:

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Graph displaying Pareto effects (N.B. Only first order effects are shown):



Sorting out confounding factors

To make sure we are not being fooled by confounded effects we run a full factorial with the top three factors:

	Parameter name	User variable name	In category	Parameter levels	Reference value	StdDeviation	
	IRcurv	IRcurv	model	[-50*um, 50*um]	50*um		
:	REcurv	REcurv	model	[-300*um, -200*ur	-250*um		
	RaIR	RalR	model	[0.01*um, 0.2*um]	0.09*um		
	RaRE	RaRE	model	[0.02*um, 0.06*un	0.048*um		
	FilmThick	FilmThick	model	[0.1*um, 0.4*um]	0.1*um		
	RaCage	RaCage	model	[0.1*um, 0.3*um]	0.2*um		
,	RaGR	RaGR	model	[0.1*um, 0.3*um]	0.2*um		
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Confounding...(cont.)

We first remove all parameters except the ones with top three effects according to the screening design...:

	Parameter name	User variable name	In category	Parameter	levels	Reference value	StdDeviation	
	IRcurv	IRcurv	model	[-50*um,	50*um	50*um		
2	RaiR	RaIR	model	[0.01*um,	0.2*u	0.09*um		
3	FilmThick	FilmThick	model	[0.1*um,	0.4*un	0.1*um		
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Confounding...(cont.)

Read the results into DoEBeast and again display the Pareto effects:

▼ X DoEBeast												
<u>F</u> ile <u>V</u> iew <u>S</u> etup <u>H</u> ∈lp												
Experiment	IRcurv	=IRcurv	RalR	=RalR	FilmThick	=FilmThick	h_wear_perf	E_slip_pe				
Experiment set:/scratch/stefan/work/DoE/NewStart/DoETutcrial/simpleSRB_dealiasing_fuf3_8												
simpleSRB_dealiasing_fuf3_8_PS_1	-0.00005	-5e-5	0.00000001	le-8	0.000004	4e-7	-4.10617850832296e-8	-2.06777270507				
simpleSRB_dealiasing_fuf3_8_PS_2	-0.00005	-5e-5	0.00000001	1e-8	0.000001	le-7	-4.5152042105201e-8	-2.63302075195				
simpleSRB_dealiasing_fuf3_8_PS_3	-0.00005	-5e-5	0.0000002	2e-7	0.000004	4e-7	-4.04519795438318e-8	-2.09377734375				
★ simpleSRB_dealiasing_fuf3_8_PS_4	0.00005	5c 5	0.0000002	2c 7	0.000001	lc 7	4.13939176269196c 8	3.07225683593				
simpleSRB_dealiasing_fuf3_8_PS_5	0.00005	5e-5	0.00000001	1e-8	0.000004	4e-7	-4.04662507946796e-8	-1.91952124023				
simpleSRB_dealiasing_fuf3_8_PS_6	0.00005	5e-5	0.00000001	1e-8	0.000001	le-7	-4.46522285812989e-8	-2.61188110351				
simpleSRB_dealiasing_fuf3_8_PS_7	0.00005	5e-5	0.0000002	2e-7	0.000004	4e-7	-4.00586657178792e-8	-2.05181762695				
simpleSRB_dealiasing_fuf3_8_PS_8	0.00005	5e-5	0.0000002	2e-7	0.000001	le-7	-4.07141556024726e-8	-2.99404663085				
	-		^	-	*		- -	·				



Confounding...(cont.)

Aha! *Ircurv* was confounded by the second order effect *RaIR*FilmThick*:



Optimising with response surface

Only two factors left. Let's optimise the model with regard to them. Use a space-filling design (Sobol):

	Parameter name	User variable name	In category	Parameter	levels	Reference v	alue	StdDeviation		
1	RalR	RalR	model	[0.01×um,	0.2 * เ	0.09*um				
2	FilmThic<	FilmThick	model	[0.1*um,	0.4*ur	0.1*um				
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			Apply				Can	el		

Optimising...(cont.)

Export the results to a file readable by Minitab:

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<u>F</u> il	e <u>∨</u> iew <u>S</u> etup <u>H</u>	<u>l</u> elp								
1	Open Ctrl+O	iment	RalR	=RalR	FilmThick	=FilmThick	h_wear_pe			
	Export //stefan/work/DoE/NewStart/DoETutorial/simpleSRB_responsesurf_Sobol_40									
×	simpleske_respon	sesurf_Sobol_40_PS_1	1.4453125e-8	1.4453125e-8	2.1953125e-7	2.1953125e-7	-4.10584668486			
×	simpleSRB_respon	sesurf_Sobol_40_PS_2	1.09453125e-7	1.09453125e-7	3.6953125e-7	3.6953125e-7	-3.92418080252			
×	simpleSRB_respon	sesurf_Sobol_40_PS_3	1.56953125e-7	1.56953125e-7	1.4453125e-7	1.4453125e-7	-3.96773955912			
×	simpleSRB_respon	sesurf_Sobol_40_PS_4	6.1953125e-8	6.1953125e-8	2.9453125e-7	2.9453125e-7	-3.99585964316			
×	simpleSRB_respon	sesurf_Sobol_40_PS_5	8.5703125e-8	8.5703125e-8	1.0703125e-7	1.0703125e-7	-4.05336351150			
×	simpleSRB_respon	sesurf_Sobol_40_PS_6	1.80703125e-7	1.80703125e-7	2.5703125e-7	2.5703125e-7	-3.97504962279			
×	simpleSRB_respon	sesurf_Sobol_40_PS_7	1.33203125e-7	1.33203125e-7	1.8203125e-7	1.8203125e-7	-3.92890520117			
×	simpleSRB_respon	sesurf_Sobol_40_PS_8	3.8203125e-8	3.8203125e-8	3.3203125e-7	3.3203125e-7	-3.99238508919			
×	simpleSRB_respon	sesurf_Sobol_40_PS_9	5.0078125e-8	5.0078125e-8	1 .6328125e-7	1.6328125e-7	-4.05206606046			
×	simpleSRB_respon	sesurf_Sobol_40_PS	1.45078125e-7	1.45078125e-7	3.1328125e-7	3.1328125e-7	-3.91294001644			
•	simpleSRR respon	sesurf Sabal 40 PS	1 92578125e-7	1 92578125e-7	2 38281 25e-7	2 3828125e-7	-4.00270359079			



Optimising...(cont.)

The response surface:





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Sensitivity analysis:

If the user knows the standard deviations of his model parameters he can setup a design that lets DoEBeast compute approximations of the mean and standard deviations of output data.

Derivatives are computed as finite-differences.

$$\mu_y pprox f_y(x_1,\ldots,x_n) + rac{1}{2}\sum_{i=1}^n rac{\partial^2 f_y(x_1,\ldots,x_n)}{\partial x_i^2} \sigma_i^2$$

$$\sigma_{y} \approx \sqrt{\sum_{i=1}^{n} \left(\frac{\partial f_{y}(x_{1},\ldots,x_{n})}{\partial x_{i}}\right)^{2} \sigma_{i}^{2}}$$

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Other features: Parallel coordinate plot

DoEBeast can plot results in several ways.

Parallel coordinate plot:



Parallel coordinate plot, cont ...

Restrict FilmThick and RalR



Other features: Pareto optimal plot

Pareto optimal front. Useful when more than one criteria is important:



Conclusion – Practical DFSS simulation

Reduce the number of parameters, i.e., screening designs. Investigate confounding effects. Do full DoE for remaining parameters (very few). Investigate robustness.





3

Parallel Computation



Spherical Roller Thrust Bearing (SRTB)





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DEA Cluster – 356 cores

1U rack nodes [76 cores]:

- $16 \times \text{Opteron 248}$ (single core 2.2GHz), 2GB memory
- $60 \times Opteron 250$ (single core 2.4GHz), 2GB memory

IBM Blade Centers [280 cores]:

- \bullet 3 \times 14st IBM BladeServer HS21 XM
 - 2 × AMD Opteron 2218 (Dual core 2.6GHz) [3*14*2*2 = 168 Cores]
 - 4GB RAM [168GB]
- \bullet 1 \times 14st IBM BladeServer HS21 XM
 - 2 × Intel XEON E5420 (Quad core 2.5GHz) [14*2*4 = 112 Cores]
 - 16GB RAM (8 × 2GB) [224GB]



IBM BladeCenter®



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Neolith cluster at NSC – 6440 cores

Hardware and Performance:

805 Nodes (HP ProLiant DL140 G3)
Two Intel Xeon E5345 Quad Core Processor 2.33GHz per Node
16GB or 32GB RAM per node
Infiniband ConnectX interconnect
Combined peak performance of 60 Tflops

Software:

Operating System: CentOS 5 x86_64
Resource Manager: SLURM
Scheduler: MOAB
MPI: OpenMPI and Scali MPI





NVIDIA FERMI a future platform?

Hardware and Performance:

16 Streaming Multiprocessors (SM)
32 CUDA cores per SM
4 Special Function Units per SM
64 KB Shared Memory/L1 Cache
ECC Memory Support
Single Precision Floating Point Capability: 512 FMA ops/clock
Double Precision Floating Point Capability: 256 FMA ops/clock
Support for up to 16 concurrent Kernels



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Use simulation early in the product development process. The Six Sigma/DFSS effort stimulate use of analytical tools. Heavy simulations & Parametric studies:

- Eliminate parameters with screening designs.
- Find optima with space filling designs.
- Check robustness in design points.



