

Paper Distributing System Tutorial (AutoDesign)





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Edition Note

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Outline of Tutorial Sample C

Model	Description
	Paper Distributing System Design Problem:
Sample_C	This design is a robust design and a 6-sigma design problem. Especially, 3 variables are noise factors and 2 variables are random design variables. Unlike Taguchi approach or other design tools, AutoDesign helps the designers to define a robust design formulation and 6-sigma constraints easily. Also, this problem results show how AutoDesign is efficient to solve a robust design and a 6-sigma constraint problem.
	Key Point: Study the conceptual differences between a robust design and 6-sigma design. Also, understand how AutoDesign defines the noise factors and random design variables.



Paper Distributing System Problem

Robust Design Optimization differs from the deterministic design optimization you just performed in Sample-A and Sample-B, in that it



takes into account the variability of the components which make up the system being optimized. For example, if temperature fluctuation or manufacturing conditions caused variability in the front link angle, you could measure this variability and input the standard deviation into the robust design optimization. The optimization would then give results which would tell you the variability of the system performance, and therefore aid in the design of a system robust to the variation of its individual components.

RecurDyn AutoDesign allows you to define the sigma level to which you want to optimize. That is, you can define the "percent feasible", or the fraction of the produced systems which will satisfy the quality constraints. A common standard is to design to 6-sigma, which means that 99.999998% of the produced systems will satisfy the quality constraints. For more information on robust design optimization and design for 6-sigma (DFSS), refer to the **RecurDyn Theoretical** and **Guideline Manual**.

Open files related in Sample-C							
Sample	<install dir=""> \Help \Tutorial \AutoDesign \ PaperDistributingSystem \Examples \ Sample_C1.rdyn</install>						
Colution	1	<install dir=""> \Help \Tutorial \ AutoDesign \ PaperDistributingSystem \Solutions \ Sample_C1.rdyn</install>					
Solution	2	<install dir=""> \Help \Tutorial \ AutoDesign \ PaperDistributingSystem \Solutions \ Sample_C2.rdyn</install>					

Note: If you change the file path at discretion, it can be located in any folder that you specify.

Chapter

Loading the Model and Viewing the Animation

To load the base model and view the animation:

- RecurDyn
- 1. On your **Desktop**, double-click the **RecurDyn** icon.
- 2. **RecurDyn** starts and the **Start RecurDyn** dialog box appears.
- Close Start RecurDyn dialog box. You will use an existing model. In the Quick Access toolbar, click the Open and select 'Sample_C1.rdyn' from the same directory where this tutorial is located. The MTT2D appears in the modeling window.
- Double-click the model on the screen to enter MTT2D toolkit. Then, Model name is changed from Model1 into MTT2D@Model1 on the left upper part in screen.

5. Click the **Dynamic/Kinematic** button.

Start RecurDyn New Model Name Model1 ▼ Setting Unit MMKS(Millimeter/Kilogram/Newton/Second) <u>G</u>ravity -Y ▼ Setting <u>о</u>к Open Model Browse Icons -Recent Models Show 'Start RecurDyn' Dialog when starting



►

6. Click the **Play** button.

The sheet runs through the upper and lower baffles and reaches to the second tray.







Design Variables

Design variables will be the factors of the model which you can control. Figure C-2-1 and Figure C-2-2 are the window and the diagram showing these factors on the model.

Properties of SheetGrou	p1 [Current Unit : N	/kg/mm/s/deg	1]			
General Sheet Group Output						
Start Point 800., 787., 0	Pt Direction Poin	t 700., 787., 0	Pt			
Folding Sheet	Point List	Refresh Prev	view			
Number of Segment	54					
Segment Length 4. Pv						
Sheet Thickness PV_thickness Pv						
✓ Initial Velocity 1020.5 Pv						
Density	6.96e-07	Pv				
Voung's Modulus		PV_E	Pv			
Damping Factor	✓ ✓ Damping Factor SH_C					
Sheet Curl Radius	Sheet Curl Radius PV_SheetCurlR Pv					
Hold Down the Noise of Sheet Contact Forces						
Update Geometry Info	Update Geometry Information Automatically					
Air Resistance Coeffici	ent Constant	2.3				
	ОК Са	ancel Aj	oply			

Figure C-2-1 Three design variables for random constants

In the **SheetGroup1** dialog, the thickness, young's modulus and curl radius are selected as $DV1 \sim DV3$. These variables are un-controllable factors from the viewpoint of mechanism designers. Thus, we consider them as random constants.



Figure C-2-2 Two design variables with tolerances

In Figure C-2-2, the vertical locations of two guides are selected as design variables. In MTT2D, the guide positions cannot be defined by using parametric values. Thus, they are not design variables directly. To overcome this situation, we introduce the motion that can include the parametric values. Two motions use the following expressions, respectively.

- PV_Yupper*STEP(TIME, 0, 0, 0.01, 1)
- PV_Ylower*STEP(TIME, 0, 0, 0.01, 1)

Defining the Design Variables

To create a design parameter:



1. From the **AutoDesign** menu, click **Design Parameter**. This will bring up the Design Parameter List dialog shown below.

 Name	Туре	Prop.	Descripti	Curr	LB	UB	Design Cost	DP Form	DV

- 2. Click **Create** to create a new design parameter. In the Direct Relation dialog that appears, change the name from DP1 to **DP_SheetCurlFactor**.
- 3. Press **PV** to bring up the Parametric Value List dialog. Select the **PV_SheetCurlFactor** parametric value by clicking on its name. When selected, it should be highlighted in blue, as shown at below.

Pa	Parametric Values							
	No	DP	Name	Value		Comment		
	1		PV_SheetCurlFactor	0.	Е			
	2		PV_SheetCurlRadius	ExSheetCurlRa	Ε			
	3		PV_E	6200.	Ε			
	4		PV_thickness	0.2	Ε			
	5		PV_Yupper	-0.31	E			
	6		PV_Ylower	-0.22	Ε			

4. Click **OK** to choose this as the design parameter. Back in the Direct Relation dialog, define upper and lower bounds (**-50, 50**). Enter a description ("**Paper Curl Factor**") in the Description field. When completed, the dialog should appear as shown at below.

Direct Relation	
Name	DP_SheetCurlFactor
Parametric Value	PV_SheetCurlFa Pv
Current Value	0. R
Lower Bound	-50.
Upper Bound	50.
Description Paper Curl Fac	tor
DP Form	Value
ОК	Cancel

- 5. Press **OK** to return to the Design Parameter List dialog box.
- 6. Create design parameter for spring mount height, similarly, using the following settings:

Name	Parametric Value	Lower bound	Upper Bound	Description
DP_Modulus	PV_E	5200	7200	Paper_Modulus_E
DP_Thickness	PV_thickness	0.1	0.3	Paper_Thickness
DP_UpperPos	PV_Yupper	-1	1	Upper baffle Y loc

DP_LowerPos	PV_Ylower	-1	1	Lower baffle Y loc
-------------	-----------	----	---	--------------------

7. Return to the **Design Parameter List** dialog and check the checkboxes under the **DV** column for both of the design parameter you just created. This activates both as Design Variables, which will be used in the **Design Study** and **Design Optimizations** to follow. When completed, the Design Parameter List dialog should appear as shown at right.

Name Type Prop. Descripti Curr LB UB Design Cost DP Form DV 1 DP Direct Paper Cur 0. -50. 50. 0. Value Image: Cost DP Form DV 2 DP Direct Image: Cost Paper Mo 6200. 52 72 0. Value Image: Cost Value Image:	In Name Type Prop. Descripti Curr LB UB Design Cost DP Form DV 1 DP Direct Paper Cur 0. -50. 50. 0. Value Image: Cost DP Form DV 2 DP Direct Image: Cost DP Form DV Image: Cost DP Form DV 3 DP Direct Image: Cost DP Paper Mo 6200. 52 72 0. Value Image: Cost Value Image: Cost <th colspan="8">esign Parameter List</th>	esign Parameter List										
Name Type Prop. Descripti Curr LB UB Design Cost DP Form DV 1 DP Direct Paper Cur 0. -50. 50. 0. Value Image: Cost DP Form DV 2 DP Direct Paper Mo 6200. 52 72 0. Value Image: Cost Image: Co	I Name Type Prop. Descripti Curr LB UB Design Cost DP Form DV 1 DP Direct Paper Cur 0. -50. 50. 0. Value Image: Cost DP Form DV 2 DP Direct Paper Mo 6200. 52 72 0. Value Image: Cost Image: Cost Value	Design Parameter										
1 DP Direct Paper Cur 0. -50. 50. 0. Value Image: Cur 2 DP Direct Image: Cur 6200. 52 72 0. Value Image: Cur 3 DP_T Direct Image: Cur 0.2 0.1 0.3 0. Value Image: Cur 4 DP Direct Image: Cur -0.31 -1. 1. 0. Value Image: Cur 5 DP_L Direct Image: Cur -0.22 -1. 1. 0. Value Image: Cur	1 DP Direct Paper Cur 0. -50. 50. 0. Value Image: Constraint of the const	۹.,	Name	Туре	Prop.	Descripti	Curr	LB	UB	Design Cost	DP Form	DV
2 DP Direct Paper Mo 6200. 52 72 0 Value Image: Constraint of the	2 DP Direct Paper Mo 6200. 52 72 0. Value Image: Constraint of the	1	DP	Direct		Paper Cur	0.	-50.	50.	0.	Value	>
3 DP_T Direct Paper Thi 0.2 0.1 0.3 0. Value Image: Value 4 DP Direct Image: Value Image: Value<	3 DP_T Direct Paper Thi 0.2 0.1 0.3 0. Value Image: Constraint of the state of t	2	DP	Direct		Paper Mo	6200.	52	72	0.	Value	
4 DP Direct Upper ba -0.31 -1. 1. 0. Value Image: Comparison of the comparison of	4 DP Direct Upper ba -0.31 -1. 1. 0. Value Image: Composition 5 DP_L Direct Image: Composition -0.22 -1. 1. 0. Value Image: Composition Image: Composition Image: Composition Value Image: Composition Image: Composition<	3	DP_T	Direct		Paper Thi	0.2	0.1	0.3	0.	Value	
5 DP_L Direct Lower baf0.22 -1. 1. 0. Value ✔	5 DP_L Direct Lower baf0.22 -1. 1. 0. Value ▼	4	DP	Direct		Upper ba	-0.31	-1.	1.	0.	Value	
		5	DP_L	Direct		Lower baf	-0.22	-1.	1.	0.	Value	✓

Note: To go back and edit a design parameter, click the button under the **Prop.** column.

8. Press **OK** to close the **Design Parameter List** dialog box.

Chapter 3

Defining the Performance Indexes

Let's consider the paper distributing system as shown in Figure C-3-1. The goal of the mechanism is to design the baffler y-positions for the paper to pass through the target position nevertheless the material property (Young's modulus, thickness and curl radius etc.) variations of the paper. In this problem, the material property variations are called as 'noise factors' and the baffler positions are done as 'design variables'. If the design variables have +/- tolerances, we call them as 'random design variables'. In **AutoDesign**, the noise factors are called as 'random constants'.



To create an analysis response:



1. From the **AutoDesign** menu, click **Analysis Response**. This will bring up the Design Response List dialog as shown below.

Analysis	Response l	list				
Analysis	Response					
No	Name	Туре	Pr	Description	Treatment	PI
						V
						<u>v</u>
	eate	Insert	Basic	The Delete		
	cutt	insert	Dusic			
				ОК	Cancel	Apply

2. Click **Create** to create a new analysis response. In the **Analysis Response - Basic** dialog that appears, change the name from AR1 to **AR_Ysensor1**.

Analysis Response	- Basic
Name	AR_Ysensor1
Result Output	ExSensor EL
Treatment	End Value 🔻
Description	Y when x is 894mm
ОК	Cancel

3. Press **EL** to bring up the **Expression List** dialog. Select the **ExSensor** expression by clicking on its name. When selected, it should be highlighted in blue, as shown below.

press press	ion List ions					
No	Name	Expression		Value	Comment	-
1	Roller1Velocity	78.5*TIME	E	0		- 1
2	HardRollVelocity	-204*TIME	E	-0		
3	Sensor	SNSR(1)	E	N/A		
4	lowerslidemotion	PV_Ylower*STEP(TIME,0,	E	-0		
5	UpperslideMotion	PV_Yupper*STEP(TIME,0,	E	-0		
6	ExSensor	IF(DX(1)-894:0,0,IF(DX(1)	E	N/A		- 4
7	ExSensorError_Sq	IF(DX(1)-894:0,0,IF(DX(1)	E	N/A		
8	ExSheetCurlRadius	IF(PV_SheetCurlFactor:5	E	0		

- 4. Click **OK** to choose this as the expression to use.
- Back in the Analysis Response Basic dialog, for the Treatment, select End Value from the dropdown list. Enter a description ("Y where x is 894mm.") in the Description field. When completed, the dialog should appear as shown above.
- 6. Press OK.

Note: To go back and edit an analysis response, click the button under the **Prop.** column

- 7. Create one more analysis response using the following values:
 - Name: Error_Sum
 - Expression Name: ExSensorError_Square
 - Treatment: End Value
 - Description: Error Square

Analysis Response	Basic
Name	Error_Sum
Result Output	ExSensorError_Square EL
Treatment	End Value
Description	Error_Square
ОК	Cancel

* The **treatment parameter** is used to control how you extract a single numerical value from a curve which varies over time. For example, setting the treatment to **End Value** will assign the value of the curve at the end of simulation, while **Min Value** will assign the lowest value that the curve reaches during the simulation.

Return to the Analysis Response List window and check the checkbox under the PI column corresponding to the analysis responses you just created. This activates them as Performance Indexes, which will be used in the Design Study and Design Optimizations to follow. When completed, the Analysis Response List window should appear as shown below.

iysis	Response L	.ist				
alysis	Response					
No	Name	Туре	Pr	Description	Treatment	PI
1	AR_Ysens	Basic		Y when x is 894mm	End Value	
2	Error_Sum	Basic		Error_Square	End Value	
0	eate	Insert	Basic			
Cr	eate	Insert	Basic	▼ Delete		

- 9. Press **OK** to close the **Analysis Response List** dialog.
- 10. Save the model.



Running a Robust Design Optimization

We will now run an optimization in which the objective is to minimize the variance of position error, and constraints are set on the y-position error.

The random design variables and random constants are listed in Table C-4-1.

Description	Current Values	Deviations	Remark
Upper baffle position	-0.31	-/+ 0.05	Random Design Variable
Lower baffle position	-0.22	-/+ 0.05	Random Design Variable

Table C-4-1 List of random design variables and constants

The robust design optimization problem is defined as:

Minimize Variance

Subject to

The paper position at x=894 (mm) = Target position

and

-1.0 = < Upper baffle position -/+ deviation = < 1.0

-1.0 = < Lower baffle position -/+ deviation = < 1.0.

The value of variance is affected from the tolerance of design variables and the deviations of noise factors. Thus, the robust design optimization problem is to find the design variables to minimize the variation of position errors, which is a typical example of robust design optimization.

To run a robust design optimization:



1. From the **AutoDesign** menu, select **DFSS/Robust Design Optimization**. The **Design Variable** dialog should appear as shown below. You should define the red-box parts.

DI	SS/R	obust Desig	n Optimizatio	on							
D	esign	Variable Per	formance Inde	ex Optim	nization	Control	Result Sheet	Summ	ary Sheet		
	DV DP Description Current LB UB					Туре	Value	Statistical In	Dev.Type	Dev. Value	
	1	DP_SheetC	Paper Curl	0.	-50.	50.	Cons 🔻	0.	Random 💌	SD 🔻	30.
	2	DP_Modulus	Paper Mod	6200.	5200.	7200.	Cons 🔻	6200.	Random 💌	cov 👻	0.1
	3	DP_Thickn	Paper Thic	0.2	0.1	0.3	Cons 🔻	0.2	Random 💌	SD 🔻	5.e-002
	4	DP_Upper	Upper baff	-0.31	-1.	1.	Varia 🔻	0.	Random 💌	SD 🔻	5.e-002
	5	DP_LowerP	Lower baff	-0.22	-1.	1.	Varia 💌	0.	Random 💌	SD 🔻	5.e-002

Unlike the design optimization, three selections are newly shown. They are 'Statistical Info', 'Dev. Type' and 'Dev. Value'. The detail descriptions of them are explained in 'Guideline manual. In the 'Statistical info', you can define which variables are 'random' or 'deterministic'. If the variable has tolerance or deviation, then it is 'random'. Otherwise, it is a 'deterministic' variable. In the 'Dev. Type', you can define that the deviation of variable is an absolute magnitude or the ratio of design value. 'SD' denotes the absolute magnitude. 'COV' does the relative ratio. Paper properties are defined as 'random constant' because they are only noise factors.

- 2. Click the **Performance Index** tab.
- 3. Change the objective function according to the table below.

AR	Definition	Goal	Weight/Limit Value	Robust Index	Alpha Weight
AR_Ysenso	Constraint	EQ	12.3	NA	NA
r1					
AR_Ysenso	Objective	MIN	1	1	0
r1	-				

It is noted that AR2 is not used in **Sample_C1**.

After making the changes, the dialog should appear as shown below. The grey part represents the deactivated values.

۵)FSS/F	obust	Design C	Optimization								
ſ	Design	Variab	le Perfo	rmance Index C)ptimization Cor	ntrol	l Resu	lt Sh	eet Summary Shee	t		
	PI	Use	AR	Description	Definition		Goa	1	Weight/Limit Va	Robust Index	Alpha Weight	
	1	$\mathbf{\overline{\mathbf{v}}}$	A 🔻	Y when x is 8	Constraint	•	EQ	•	12.3	1.	1.	
	2		A 🔻	Y when x is 8	Objective	•	MIN	•	1.	1.	0.	

In **DFSS/Robust design optimization**, the design objective is internally represented as:

PI = Weight*(AR*Alpah_Weight+Sigma*Robust_Index)

The value of 'Weight' represents the relative importance of the selected AR in the multiple objectives. Alpha_Weight and Robust_Index are the flags of two responses. These values should be `0' or `1'. `0' represents that the corresponding response is neglected.

If Alpha_Weght=1 and Robust_Index=0, then minimize Weight*AR.

If Alpha_Weght=0 and Robust_Index=0, then minimize Weight*Sigma.

If Alpha_Weght=0 and Robust_Index=1, then minimize Weight*(AR+Sigma).

If both values are '0', then make no design formulation. It is a logical error.

- 4. Click on the **Optimization Control** tab.
- 5. Change the settings so that they appear as shown below.

DFSS/Robust Design Optimization	
Design Variable Performance Index Optimization Control Result Sheet Si	ummary Sheet
DOE Meta Modeling Methods	Methods
Convergence Tolerance	
Objective Change Rate in Consecutive Iterations	5.e-002
Equality Constraints	1.e-003
Inequality Constraints	1.e-003
Maximum Iteration of SAO	30.
Convergence Relaxation Control	OFF 👻
DFSS/Robust Design Control	
Validation Type	Validation
Sample Points for Validation	8
Variance Estimation Method	Random Sampling 🔻
	Dynamic/Kinematic
	Number of Trials 21
Analysis Setting	Execution
	OK Cancel Apply

6. For the convergence tolerance, the default values are used. Unlike the design optimization module, DFSS/Robust Design Control is newly shown. In the above figure, the red color box shows the DFSS/Robust Design control. The detail information of them is explained in 'Guideline Manual'. As you can see, AutoDesign solves the robust design problem by using the meta-models.

Although the analysis responses are validated when the meta-model is updated during optimization process, the standard deviation is estimated from meta-models. Thus, the variance values of final design are not validated. In the **'Validation Type**', there are three types such as 'None', '**Validation**' and '**Validation & Re-Optimization**'. When '**Validation**' is selected, **AutoDesign** performs the exact analyses for the sampled

points within the deviation ranges at the final design. Then, estimate the sample variance. In the 'Variance Estimation Method', there are two types such as 'Taylor Series method' and 'Random Sampling method', which are the variance approximation method from meta-models, which are explained in 'Guideline manual'.

7. Check the analysis setting by clicking the **Analysis Setting** button. As explained in Sample-A and Sample-B, it is noted that the accuracy of analysis responses depends on the number of STEP.

D	ynamic/Kinematic Analysis		×
6	eneral Parameter Initial Conditi	on	
	End Time	0.1 Pv]
	Step	300. Pv]
	Plot Multiplier Step Factor	1. Pv]
	Output File Name	Robust_rbf_RV	
	nclude		_
	Static Analysis		
	Eigenvalue Analysis		
	State Matrix		
	Frequency Response Analysis		
	Hide RecurDyn during Simulat	ion	-
	Display Animation		
	Gravity X 0. Y -9806.65	Z 0. Gravity	
	Unit Newton - Kilogra	m - Millimeter - Second	
		OK Canc	el

8. Click the **Execution** button to run the optimization with the settings you just made. Then, you can see the summary of the optimization formulation shown at below. Then, click the **OK** button. The optimization will be progressed.

	DV	Description	Current	LB	UB	Туре	Value	Statistical In	o Dev.Ty	pe Dev.	Value
1	DP_SheetC	. Paper Curl	0.	-50.	50.	Const	0.	Random	SD	3	0.
2	DP_Modulu	Paper Mod	6200.	52	72	Const	6200.	Random	COV	/ 0	.1
3	DP_Thicknes	s Paper Thick	0.2	0.1	0.3	Const	0.2	Random	SD	5.e-	-002
4	DP_UpperPo	s Upper baffl	-0.31	-1,	1.	Variable	0.	Random	SD	5.e-	-002
5	DP_LowerPo	s Lower baffl	-0.22	-1,	1.	Variable	0.	Random	SD	5.e-	-002
1	AR Y wh	en x is 89 C	onstraint	1	EQ		12.3		1.	1.	_
_											
eta -	- Model										
eta -	- Model Initial DOE M	ethod				Discret	e Latin H	lypercube Des	gn		_
eta -	- Model Initial DOE M Meta-Model N	ethod			Rac	Discret lial Basis F	e Latin H unctions	lypercube Des Model(Multi-	gn Quadratic)		
eta -	- Model Initial DOE M Meta-Model N Polynomina	ethod Athod IType A			Rac	Discret lial Basis F	e Latin H unctions A	lypercube Des Model(Multi- uto	gn Quadratic)		

9. To view the result of the design optimization after optimization is completed, click the **Result Sheet** tab.



The optimization process is converged at the 2th iteration. The final design gives that AR1 is 12.29 and its' approximate Sigma is 0.07 and the sample Sigma is obtained as 0.07. The error between the approximate Sigma and the sample Sigma is caused from the accuracy of meta-models. When the sample Sigma is greater than the estimated ones, you may re-optimize by using **'Get from Simulation History**'.

10. Now, check the analysis results in '**Summary Sheet**'. When constructing the metamodels, the values of design variables and constants are sampled within their bounds and deviations. If you define the parameter as constant, however, they are not changed during optimization process.

In the list of design variables, DV4 and DV5 are changed from (-0.31, -0.22) to (-0.34, -0.21) because they are design variables.

In the list of analysis responses, the optimum values are the analysis responses for the optimum design values and the sample STD (standard deviations) values are evaluated from the sample points for validation. See the optimization control menu at the above Step 7.

		t Design Optim	nization								
sign	Varia	ble Performanc	ce Index Op	timizat	ion Control Res	ult Sheet	Summary S	heet			
esig	n Vari	ables									
No	D	Name	De	scriptio	n Optim	Current	LE	3	UB		
4		DP_UpperPos	Upper	baffle	Y loc -0.349170	5233	-0.31	-1		1.	
5 DP_LowerPos Lower			baffle	Y loc -0.211278	9799	-0.22	-1		1.		
naly	sis Re	sponses									
1	No	Na	ame		Description	n	Op	otimum		Sampled STD	
	1	AR_Ys	sensor1		Y when x is 89	4mm	12,299	3491998287	7.015	87412634486e-002	1
	2	Erro	r_Sum		Error_Squa	re	4.2354086	3010544e-00	6.455	26077318347e-003	
enor	Tormance Indexes										
No		Description	Definition	Goal	Weight/Limit Va	lue Pok	oust Index	Alpha Weig	ht Dal	aved Pohust Index	_
No 1	AR AR	Description Y when x is	Definition Constraint	Goal EQ	Weight/Limit Va	lue Rot	ust Index	Alpha Weig	ht Reli	axed Robust Index	
No 1 2	AR AR AR	Description Y when x is Y when x is	Definition Constraint Objective	Goal EQ MIN	Weight/Limit Va 12.3 1.	lue Rot	1. 1.	Alpha Weig 1. 0.	ht Reli	axed Robust Index	
No 1 2 SAO Initi	AR AR AR	Description Y when x is Y when x is E Method	Definition Constraint Objective crete Latin H	Goal EQ MIN	Weight/Limit Va 12.3 1.	lue Rot	1. 1.	Alpha Weig 1. 0.	ht Rela	axed Robust Index	
No 1 2 SAO Initi	AR AR AR al DO	Description Y when x is Y when x is E Method Disodel	Definition Constraint Objective crete Latin Hj dial Basis Fur	Goal EQ MIN ypercut	Weight/Limit Va 12.3 1. De Design Model(Multi-Qua	lue Rob	Dust Index 1. 1. Polyne	Alpha Weig 1. 0.	ht Rela	axed Robust Index	
No 1 2 SAO Initi Initi	AR AR AR al DO al DO al San	Description Y when x is Y when x is E Method Disodel Rac nple Runs	Definition Constraint Objective crete Latin Hj dial Basis Fur 21 SA	Goal EQ MIN ypercub actions O	Weight/Limit Va 12.3 1. De Design Model(Multi-Qua	dratic)	Dust Index 1. 1. Polyne Validat	Alpha Weig 1. 0. ominal Type [tion 8	ht Rela	axed Robust Index Auto aluations 31	
No 1 2 SAO Initi Met Initi	AR AR AR al DO a - Mo al San timal D	Description Y when x is Y when x is E Method Disodel Rac nple Runs Design D:\t	Definition Constraint Objective crete Latin Hj dial Basis Fur 21 SA test_tmp\Sam	Goal EQ MIN ypercut nctions O	Weight/Limit Va 12.3 1. De Design Model(Multi-Qua 	dratic) 2(0) _rbf_RO_	Dust Index 1. 1. Polyne Validat 002	Alpha Weig 1. 0. ominal Type [tion 8	ht Rela	Auto	
No 1 2 SAO Initi Initi Opt	AR AR.	Description Y when x is Y when x is Y when x is E Method Disodel Rac nple Runs Design D:\t e New Optimum	Definition Constraint Objective crete Latin Hy dial Basis Fur 21 SA test_tmp\San Model	Goal EQ MIN ypercut actions O nple_C1 A	Weight/Limit Va 12.3 1. De Design Model(Multi-Quan 	dratic) _rbf_RO_ odel	Dust Index 1. 1. Polyna OU2	Alpha Weig 1. 0. ominal Type [tion 8	ht Rela	Auto Auto Auto Spen Summary file	

In the SAO summary, the total number of evaluations is 31 that include the 21 evaluations for the initial sampling.

11. Save the model. In order to study 6-Sigma design, save as the model as **Sample_C2**.

Chapter 55

Running a 6-Sigma Design Optimization

Load the model '**Sample_C2.rdyn'**. As you can see, 6-Sigma design uses the same design variables and analysis responses as "Sample_C1". Only the design formulation is different from the robust design. Figure C-5-1 shows the design variables, which is the same as "Sample_C1".

C	FSS/R	obust Desig	ın Optimizatio	on											
Design Variable Performance Index Optimization Control Result Sheet Summary Sheet															
	DV	DP	Description	Current	LB	UB	Туре		Value	Statistical In	ı	Dev.Typ	e	Dev. Value	
	1	DP_SheetC	Paper Curl	0.	-50.	50.	Cons	•	0.	Random	•	SD	-	30.	
	2	DP_Modulus	Paper Mod	6200.	5200.	7200.	Cons	•	6200.	Random	•	cov	-	0.1	
	3	DP_Thickn	Paper Thic	0.2	0.1	0.3	Cons	•	0.2	Random	•	SD	-	5.e-002	
	4	DP_Upper	Upper baff	-0.31	-1.	1.	Varia	•	0.	Random	•	SD	-	5.e-002	
	5	DP_LowerP	Lower baff	-0.22	-1.	1.	Varia	•	0.	Random	•	SD	-	5.e-002	

Figure C-5-1 The design variables for 6-Sigma Design Optimization

To run a robust design optimization:

Let's consider the 6-sigma design optimization formulation, shown in Figure C-5-2. The design goal is to minimize the sum of error, which represents (Y_position - 12.3)**2. From the viewpoint of 6-sigma design, the Y_position should satisfy the following inequality relations.

AutoDesign describes the above relation by using two inequality constraints.

$$Y_{position} + 6*Sigma = < 15.3$$

The signs of -' and +' positioned before sigma are automatically defined for the inequality constraint types such as 'GE' or 'LE'. Hence, you can define those two inequality constraints shown in Figure C-5-2. The grey colored parts are deactivated.

As explained in "Sample_C1". DFSS/Robust design module defines the design objective as

PI = Weight*(AR***Alpah_Weight**+Sigma***Robust_Index**)

For this problem, we want to minimize only AR2. Thus, we define the robust index = 0 and the alpha weight = 1.

0	FSS/R	obust	Design (Optimization								
Į	Design	Variab	le Perfo	rmance Index C	ptimization Co	ntro	l Resu	lt Sh	eet Summary Shee	t		
l	PI	Use	AR	Description	Definition		Goa	al	Weight/Limit Va	Robust Index	Alpha Weight	
l	1		A 🔻	Y when x is 8	Constraint	-	LE	•	15.3	6.	1.	
	2	~	A 🔻	Y when x is 8	Constraint	-	GE	•	9.3	6.	1.	
	3	\checkmark	E 🔻	Error_Square	Objective	•	MIN	•	1.	0.	1.	

Figure C-5-2 Design optimization formulation for 6-sigma constraints

- 2. Click the **Optimization Control \rightarrow DOE Meta Modeling Methods**
- 3. In order to save the computational time, we will use the analysis results from "Sample_C1". Uncheck 'Select DOE method' and Check 'Get From Simulation History". Then, the Get From Simulation History button will be activated. Click the Get From Simulation History button.

E & Meta Modeling Methods	
Auto Selection	
DOE Method	Meta Modeling Method
Select DOE Method	◯ Simultaneous Kriging/DACE Model *
Classical Method Generalized Small Composite Design Central Composite Design	Radial Basis Functions Model(Gaussian) Radial Basis Functions Model(Multi-Quadratic) *
Box and Behnken Design	Polynomial Function
Number of 20 Incomplete Small Composite Design-1 Incomplete Small Composite Design-2	 Constant Model Linear Model Complete Quadratic Model
Get From Simulation History	Pure Quadratic Model Pure Cubic Model Hybrid Linear
	* Recommended

4. Then, you can see the simulation history as below. Then, check the runs in the '**Get'** column. In order to compare 6-sigma design optimization with the robust design result,

No	Plot	Get	Update	Export	Design Cost	Description of	Success/Fa	Violati	AR1	AR2	DV1	DV2	DV3	DV4	DV5	F
7	Γ	~			0.	Initial Run Bloc	Success	-	11.761	0.2901	-18.42	6357.8	0.2578	1.	5.26315	1
8		~			0.	Initial Run Bloc	Success	-	10.719	2.4995	-44.73	5726.3	0.1421	5.2631	-0.8947	
9					0.	Initial Run Bloc	Success	-	11.253	1.0960	44.736	5200.	0.3	0.8947	-0.2631	ľ
10					0.	Initial Run Bloc	Success	-	14.174	3.5144	-50.	5936.8	0.2368	-0.368	0.57894	
11					0.	Initial Run Bloc	Success	-	11.186	1.2389	18.421	6147.3	0.2684	0.7894	-0.3684	
12		~			0.	Initial Run Bloc	Success	-	10.712	2.5197	7.8947	7200.	0.1947	0.4736	-0.7894	ŀ
13		I			0.	Initial Run Bloc	Success	-	12.393	8.6501	23.684	6884.2	0.1315	-0.894	-0.4736	
14					0.	Initial Run Bloc	Success	-	10.404	3.5946	39.473	5831.5	0.2473	0.3684	-1.	
15					0.	Initial Run Bloc	Success	-	13.546	1.5543	28.947	6042.1	0.1842	0.2631	0.78947	ŀ
16					0.	Initial Run Bloc	Success	-	12.865	0.3202	-34.21	6568.4	0.1736	-5.263	0.26315	
17					0.	Initial Run Bloc	Success	-	13.718	2.0131	-28.94	5410.5	0.2789	0.5789	1.	
18					0.	Initial Run Bloc	Success	-	13.472	1.3741	-7.894	5515.7	0.1631	0.1578	0.68421	
19					0.	Initial Run Bloc	Success	-	11.694	0.3670	-39.47	5621.0	0.2894	0.6842	-5.2631	
20					0.	Initial Run Bloc	Success	-	13.892	2.5353	34.210	6778.9	0.2263	-0.578	0.36842	
21					0.	Initial Run Bloc	Success	-	12.226	5.4261	0.	6200.	0.2	-0.31	-0.22	
22					0.	RSA01	Success	1.3515	12.121	3.1877	0.	6200.	0.2	-0.597	-0.4601	
23					0.	RSAO1	Success	0.	12.301	1.1335	0.	6200.	0.2	-0.636	-0.4034	F
24					0.	RSAO1	Success	0.	12.300	9.7532	0.	6200.	0.2	-0.636	-0.4035	L
Jpd ()	ate Mo New N	odel — Nodel	OCurre	nt Model	Update	Select - Target From	Plot		• (Clear heck	Plot Fa	ctor AR	Import File		Plot Delete	

select only the results of 'Initial Runs for Meta Model'. Finally, click the OK button.

- Now, you will back to the window of DOE Meta Modeling Methods. Then, select `Radial Basis Function Model(Multi-Quadratics)' for meta-model and 'Auto' for polynomial type.
- 6. To Return the **'Optimization Control**' tab, click **Close** button. We will the same convergence tolerances and the same validation information. Thus, click the **Execution** button. If all information is the same as Figure C-5-3, then push the **OK** button.

No DV		Description	Current	LB	UB	Туре	Value	Statistical Info		Dev.Typ	Dev. Value	
1	DP_SheetC		Paper Curl	0.	-50.	50.	Const	0.	Ra	indom	SD	30.
2	DP_Mo	odulus	Paper Mod	6200.	52	72	Const	6200.	Ra	indom	COV	0.1
3	DP_Thi	ickness	Paper Thick	0.2	0.1	0.3	Const	0.2	Ra	ndom	SD	5.e-002
4	DP_Up	perPos	Upper baffl	-0.31	-1,	1.	Variable	0.	Ra	ndom	SD	5.e-002
5	DP_Lov	werPos	Lower baffl	-0.22	-1.	1.	Variable	0.	Ra	ndom	SD	5.e-002
-	AK	T WHEN	TX IS 05 C		-	GE		9.5		0		0,
		Linoi		bjetire								·
	- Model				_	_		_	_			
eta		OE Met	thod	Get From Simulation History								
eta	Initial D	odel Me	thod	Radial Basis Functions Model(Multi-Quadratic)								
eta	Initial D Meta-M			Auto								
eta	Initial D Meta-M Polyno	ominal T	iype									

Figure C-5-3 Summary of 6-Sigma design optimization formulation

7. When the optimization process is converged, click the **Result Sheet** tab. Then, the optimization results are shown in Figure C-5-4. The final design gives that AR1=12.299 and the estimate Sigma and the sample Sigma are 0.053 and 0.062, respectively. In the robust index check, the relation of 'AR1+/-6*0.062 satisfies the limit values of 9.3 and 15.3. Thus, the relaxed values for robust indexes are obtained as '6'. For more information of 6-sigma design, refer to the 'Guideline Manual'.



Figure C-5-4 Convergence history of 6-Sigma design optimization

Now, compare the optimization results of `Sample_C1' and `Sample_C2'. Both designs have different design variables (DV4 & DV5) but give nearly equal values of the sample-Sigma. Thus, you can select one of them. For these comparisons, we think that the design result of robust design is better than that of 6-sigma design, because it gives better position of paper at the target position even though their sample variances are nearly equal.

Thanks for participating in this tutorial!