CASE 61

Reduction of Chattering Noise in Series 47 Feeder Valves

Abstract: Field reports of *chattering* inspired us to apply the Taguchi robust design technique to enhance the design of the Series 47 feeder valve to make it robust against field noise conditions. Chattering manifests itself when the feeder valve is slightly open or slightly closed. A system harmonic is created, resulting in a loud, rolling noise through the heating pipes. This noise is considered by customers to be a significant nuisance and must be minimized or eliminated.

Instead of measuring chattering noise, the proportionality among flow rate, flow area, and inlet pressure was considered as the ideal function. The experiment analyzed the level effects of six control factors and three noise factors. The zero-point proportional equation was used for the analysis. The inlet pressure to the feeder valve and the cross-sectional flow area were utilized as dynamic signals. The flow rate through the valve was used as the response.

Experimental results showed a SN ratio gain of 4.63 dB over our present design. This indicates the potential for a significant improvement in the chattering problem.

1. Introduction

Series 47 and Series 51 mechanical water feeder and low-water cutoff combinations, as well as Series 101A electric water feeders, are essential to our product mix. All three series incorporate the same feeder valve. The valve cartridge that controls the water flow is shown in Figure 1. This valve handles cold water feed at inlet pressures up to 150 psig. This project was undertaken to correct a field condition that is related to the valve, commonly referred to as *chattering*.

2. Background

To increase its reliability and life and to make it more installer-friendly, the feeder valve was redesigned in 1995. The new design incorporates a plastic (Noryl) replaceable cartridge. Valve shutoff is achieved when the moving poppet inside the cartridge is locked into place mechanically by an external stem that exerts force on the diaphragm. The configuration of the cartridge within the valve is shown in Figure 2. Internal components of the cartridge are shown in Figure 3.

Upon its introduction to the market, we began receiving complaints of valve chattering in 47-LWCO series. The 51-LWCO series received almost no complaints. As the Series 47 is used in residential boilers and the Series 51 in industrial boilers, we surmised that the high complaint level on the Series 47 was due to by homeowners' sensitivity to noise. The 101A feeder was unaffected because it has a quick-shutoff mechanism. The chattering could not

 Taguchi's Quality Engineering Handbook. Genichi Taguchi, Subir Chowdhury and Yuin Wu

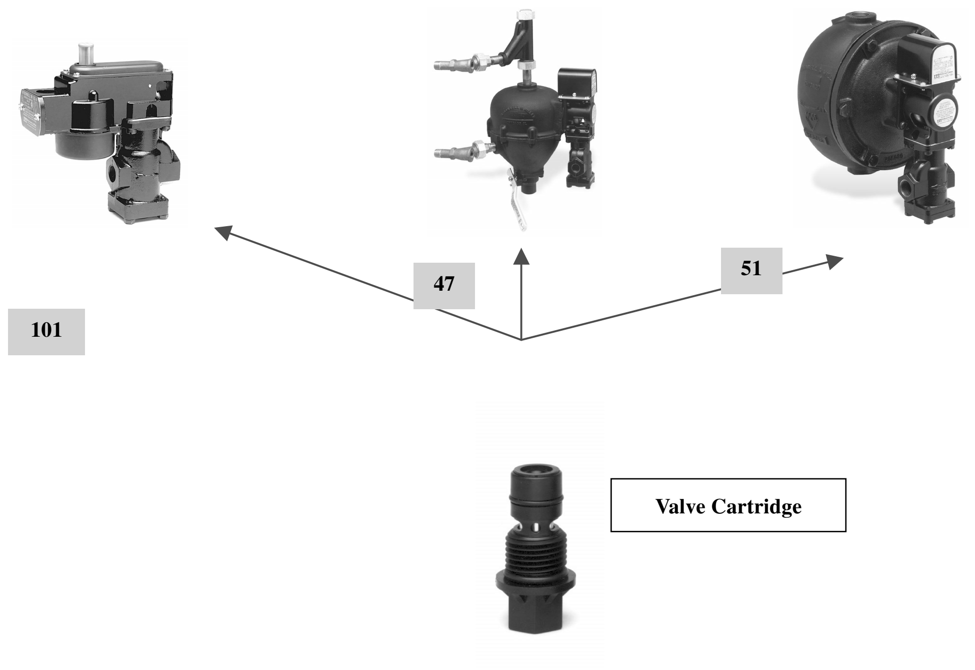

Figure 1
Feeder valve

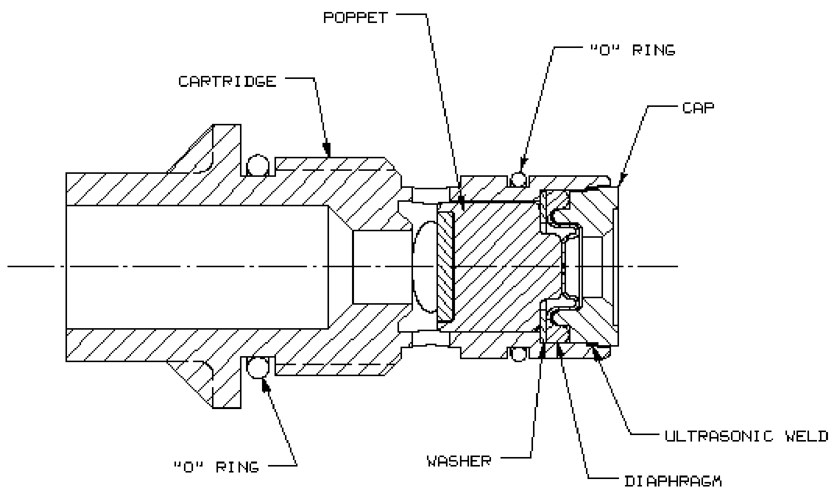

Figure 2
Cartridge within the valve

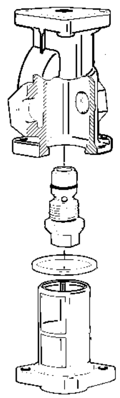

Figure 3
Internal components of the valve

be corrolated with specific system dynamics, nor could it be replicated completely in the engineering laboratory. Nevertheless, it was clear that under certain conditions the valve would cause an oscillation in the heating pipes. The resulting vibration and noise had customers, as well as manufacturer's representatives, calling for a solution.

Earlier attempts at solving the chattering noise did not follow a designed experiment methodology. Two one-factor-at-a-time solutions, in particular the quadring and the round poppet, caused ancillary difficulties and had to be reversed later. One conclusive fact was uncovered: The chattering occurred when the valve was slightly open, either right at opening or right before shutting off.

3. Objectives

The objective of this product optimization was twofold: (1) to reduce variability under field noise conditions (i.e., to maximize the SN ratio), and (2) to optimize the design for minimum flow rate of 2.0 gal/min at 40 psig (i.e., to adjust the sensitivity). This would be achieved by obtaining a consistent flow rate across the valve in proportion to the inlet water pressure and the cross-sectional flow area (Figure 4).

4. The Team

McDonnell & Miller selected a team of personnel to improve the robustness of the feeder valve under field noise conditions. The team was cross-functional, to ensure that all interests were represented and all resources accessed. The team consisted of the following people: Amjed Shafique, senior product support engineer (team leader); Azi Feifel, senior quality engineer; Nestor Galimba, quality technician; Vladimir Ulyanov, senior laboratory technician; Chris Nichols, assistant laboratory technician; and Greg Roder, product specialist.

5. Experimental Layout

Figure 5 is a P-diagram that shows the control, noise, and signal factors. Factor definitions follow. Factor levels are shown in Table 1.

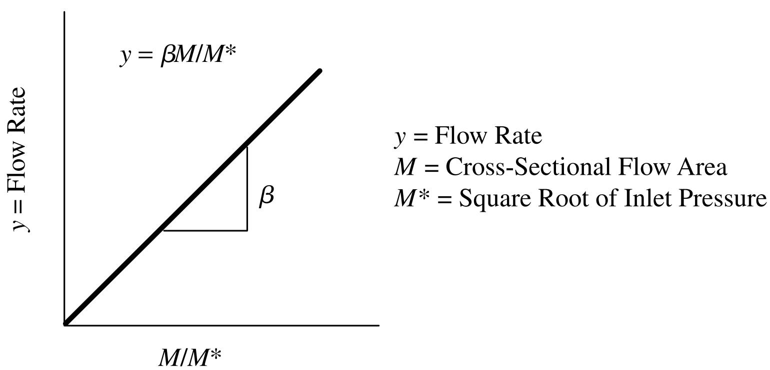

Figure 4
Ideal function

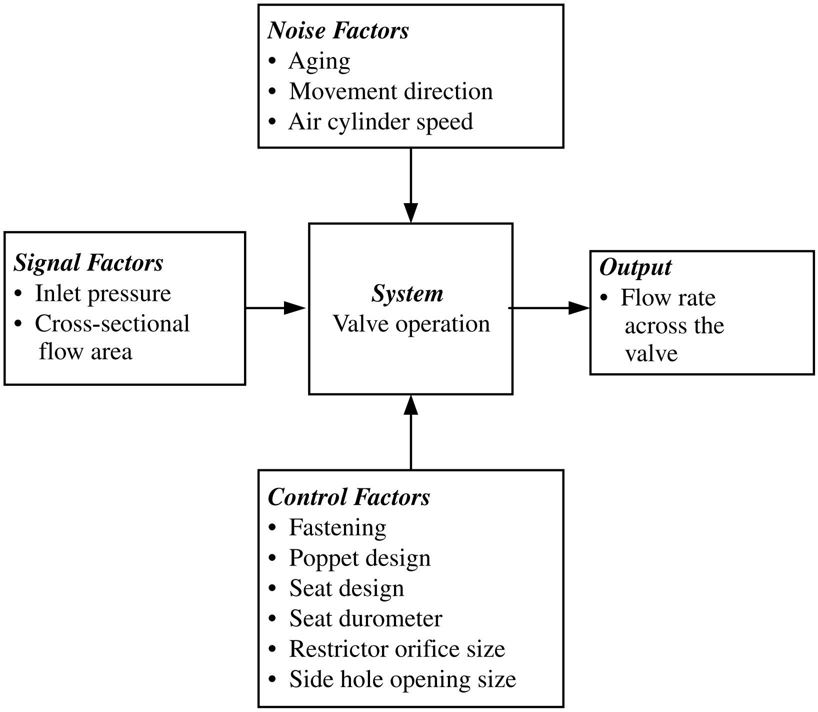

Figure 5
P-diagram

Control Factors

- *Fastening:* the cartridge poppet, either mechanically fastened to the diaphragm or unfastened, and allowed to move freely in the cylinder (see Figure 3 for a graphical depiction)
- *Poppet design:* the shape of the poppet, determining the amount of flow around the poppet
- *Seat Design:* the relative shape of the EPDM rubber seat on the poppet that is forced on the inlet orifice and shuts off the water flow
- *Durometer:* the hardness of the EPDM rubber seat on the shutoff end of the poppet
- *Restrictor size:* the diameter of the hole in the restrictor plug inserted into the hex end of the cartridge (the restrictor acts as a pressure-reducing mechanism for the inlet water feed)
- *Cartridge side hole:* the slots around the neck of the cartridge through which the water flows when the valve is open

Noise Factors

- *Aging:* controls whether or not the cartridge had been in use (the effect of age is recognized by the lasting impression of the inlet orifice on the poppet seat)
- *Air cylinder speed:* reflects the rate at which force is applied to the valve as it is shutting and opening
- *Movement direction:* controls whether the response is being measured as the valve is opening or closing

Dynamic Signal Factors

- *Inlet pressure:* the water pressure as it enters the water feeder valve. The outlet of the valve is exposed to the atmospheric pressure during testing, which is why we used inlet pressure instead of pressure drop. It is typically determined by the system pressure of the locale.

Table 1
Factor and levels

Factors		Level 1	Level 2	Level 3
Control factors				
A:	fastening	Not fastened	Fastened	
B:	poppet design	Hex	Square	
C:	seat design	Flat	Conical	Spherical
D:	durometer	80	60	90
E:	restrictor size (in.)	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{16}$
F:	cartridge side hole size (in.)	0.187	0.210	
Noise factors				
N:	aging	New	Aged	
FR:	air cylinder speed (in./sec)	0.002	0.001	
DR:	air cylinder direction	Down (as valve closing)	Up (as valve opening)	
Signal factors				
M:	inlet pressure (psig)	40	150	80
*M**:	cross-sectional flow area	Flow area calculated as valve closing or opening.		

- *Cross-sectional flow area:* the cross-sectional area between the seat and the inlet orifice as the valve is opening or shutting. This is calculated from the shutoff force.

Cross-Sectional Flow Area Calculations

- Maximum valve shutoff force occurs when the valve is held fully shut. At this point, 0% of the cross-sectional flow area is open, and flow of water through the valve has ceased.
- Minimum valve shutoff force occurs when the valve is fully open. At this point 100% of the cross-sectional flow area is open, and maximum flow through the valve occurs.
- Current valve shutoff force refers to the force exerted on the valve at any relative cross-sectional flow area between 100%, fully open, and 0%, fully closed. This value is variable as the valve opens and shuts and is recorded by the data collection system twice per second.
- The actual cross-sectional flow area percentage at any point along the spectrum is interpolated and calculated as

$$\frac{(\text{maximum shutoff force}) - (\text{current shutoff force})}{(\text{maximum shutoff force})} \times 100$$

6. Test Setup

The test setup is shown in Figures 6 and 7. Important notes:

- Inlet feed pressure, one of the dynamic signals, and air cylinder speed, the rate at which the force gauge closes and opens the valve, were regulated as part of the setup.
- Flow rate, the output response, and force to close or open the valve, used to calculate the cross-sectional flow area, were taken in real time from a flow meter and force gauge, respectively.
- As the valve opens and shuts, the flow rate and shutoff force were taken simultaneously at the rate of twice per second. The data were downloaded electronically directly into a computer spreadsheet.

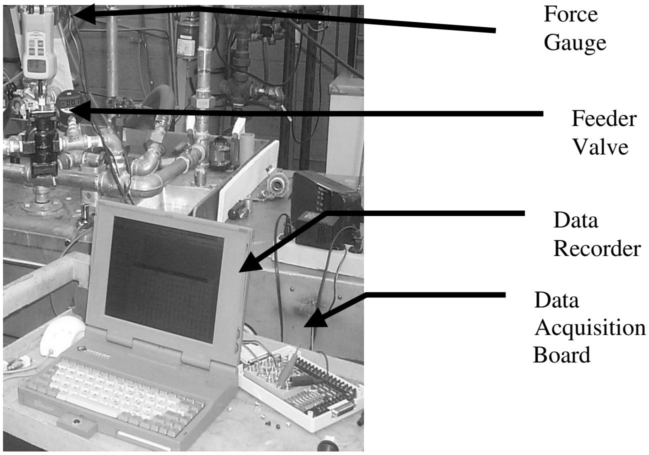

Figure 6
Test setup 1

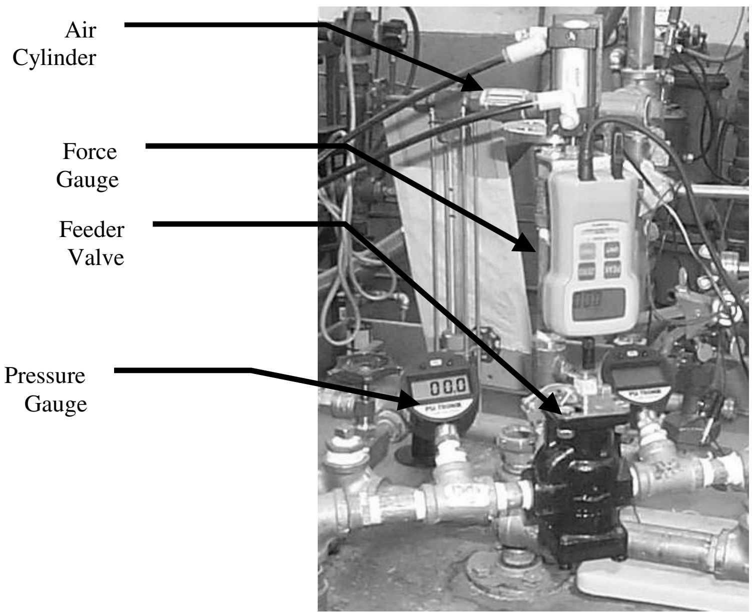

Figure 7
Test setup 2

Table 2
SN response

Level	Factor					
	A: Fastening	*B*: Poppet Design	*C*: Seat Design	*D*: Durometer	*E*: Restrictor Size	*F*: Side Hole Size
1	−6.05	−5.76	−5.90	−6.12	−7.35	−5.64
2	−5.12	−5.25	−5.93	−5.24	−4.87	−5.48
3			−4.94	−5.39	−4.55	
Delta	0.93	0.51	0.99	0.88	2.80	0.15
Ranking	3	5	2	4	1	6

7. Experimental Results and Analysis

A dynamic L_{18} orthogonal array experiment was performed to optimize the valve design. Data resulting from the experiment across the signal and noise factors are presented in the appendix for this case. As this experiment and the response were dynamic, the equations used to calculate the SN ratio and slope (β) were as follows:

$$\text{SN} = \eta_{\text{dB}} = 10 \log \frac{(1/rr_0)(S_\beta - V_e)}{V_e}$$

$$\beta = \sqrt{\frac{1}{rr_0}(S_\beta - V_e)}$$

The SN ratio and sensitivity are given in Tables 2 and 3, and the SN response graph is shown in Figure 8.

The tables show that factor *E*, the restrictor size, and then factor *C*, the seat design, had the greatest effect on the variability in the flow rate. Factor *A*, fastening, was also shown to have some effect. The graph shows the greatest SN differentials at different levels for factors *E* and *C*, with a smaller differential for factor *A*. Factors *B*, *D*, and *F* showed no significant differential in SN ratios at the various levels.

Factor *E*, restrictor size, had by far the greatest impact on the valve flow rate. Factor *C*, seat design, also showed less impact, with fastening (factor *A*)

Table 3
Sensitivity response

Level	Factor					
	A: Fastening	*B*: Poppet Design	*C*: Seat Design	*D*: Durometer	*E*: Restrictor Size	*F*: Side Hole Size
1	0.4665	0.4702	0.4734	0.4788	0.8957	0.4800
2	0.4856	0.4877	0.5046	0.4764	0.4075	0.4680
3			0.4501	0.4728	0.1248	
Delta	0.0574	0.0751	0.0342	0.0635	0.7134	0.0455
Ranking	4	2	6	3	1	5

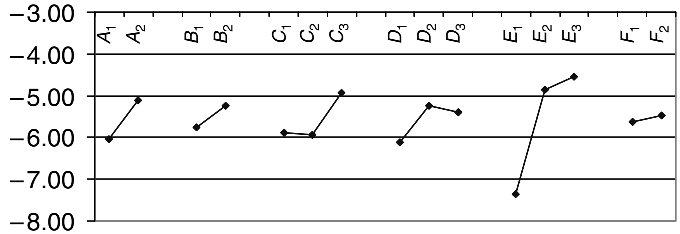

Figure 8
Response graph

shown to have less influence yet. Factor *B*, poppet design, showed no effect at all, with factors *D* and *F*, seat durometer and side hole size, showing little effect.

We applied the two-step optimization process to reduce flow rate variability and to meet minimum flow rate requirements. The optimum design will give us an average flow rate of 2.25 gal/min. The control factor levels of the optimum design are as follows:

A_2: fastened

B_1: hex

C_3: spherical

D_2: 60

E_2: 0.125 in.

F_1: 0.187 in.

8. Confirmation

Based on the robust design experimentation, design optimization would predictably result in an SN ratio gain of 5.90 dB. A confirmation run at the optimal design resulted in a 4.63-dB gain. This is not perfect; nevertheless, it shows good reproducibility and confirms the success of the experiment. Results are shown in Table 4.

9. Conclusions

To solve the water feeder valve chattering problem, a dynamic Taguchi L_{18} experiment was performed. The experiment analyzed the level effects of six control factors and three noise factors. The zero-point proportional equation was used for the analysis. The study employed a double signal, inlet pressure into the feeder and cross-sectional flow area, with flow rate through the valve used as the response.

Experimental results showed a predictive SN ratio gain of 5.90 dB. This indicates that design optimization and a significant improvement in the chattering problem could be achieved. A confirmation study using the optimal design factors resulted in a 4.63-dB gain.

Table 4
Results of confirmatory run

Design	SN	Gain	Beta	Gain
Initial production	−8.87	—	0.88	—
Optimum prediction	−2.97	5.90	0.46	−0.42
Optimum confirmed	−4.25	4.63	0.37	−0.51

The Series 47 chattering experiment was the first Taguchi robust design experiment for McDonnell & Miller. We put the robust design technique to the test by applying it to a product that has been in the field for several years and has shown a sporadic chattering problem from the beginning. Utilizing robust design techniques we were able to predict the quality of the optimum design via the SN ratio gain. Based on the 4.63-db gain, we felt that this design needs to be tested in the field for customer approval. At the same time, we started working on a new cartridge that will eliminate altogether the free-moving part in the cartridge. With the traditional design–test–build method we could not pinpoint control factors that would make the product robust against field noise conditions as explicitly as we were able to do using the Taguchi robust design method.

Acknowledgments The author expresses his sincere appreciation to Shin Taguchi of American Supplier Institute and Tim Reed of ITT Industries for their guidance throughout the experiment.

References

J. L. Lyons, 1982. *Lyons Valve Designer's Handbook*. New York: Van Nostrand Reinhold.

R. L. Panton, 1984. *Incompressible Flow*. New York: Wiley.

G. H. Pearson, 1972. *Valve Design*. New York: Pitman.

Genichi Taguchi, Shin Taguchi, and Subir Chowdhury, 1999. *Robust Engineering*. New York: McGraw-Hill.

Yuin Wu and Alan Wu, 1998. *Taguchi Methods for Robust Design*. Livonia, Michigan: ASI Press.

This case study is contributed by Amjed Shafique.

Appendix

No.	Inner Array								SN Ratio	Sensitivity
	A: Fastening	*B*: Poppet Design	*C*: Seat Design	*D*: Durometer	*e*	*E*: Restrictor Size	*F*: Cartridge Side Hole Size	*e*		
1	Not fastened	Hex	Flat	80		0.500	0.187		−8.27	0.8794
2	Not fastened	Hex	Conical	60		0.125	0.210		−4.00	0.3998
3	Not fastened	Hex	Spherical	90		0.063	0.187[a]		−1.95	0.1214
4	Not fastened	Square	Flat	80		0.125	0.187[a]		−6.62	0.4158
5	Not fastened	Square	Conical	60		0.063	0.187		−2.94	0.1318
6	Not fastened	Square	Spherical	90		0.500	0.210		−5.01	0.8376
7	Not fastened	Hex[a]	Flat	60		0.063	0.210		−4.57	0.1228
8	Not fastened	Hex[a]	Conical	90		0.500	0.187[a]		−9.58	0.9315
9	Not fastened	Hex[a]	Spherical	80		0.125	0.187		−2.73	0.3582
10	Fastened	Hex	Flat	90		0.125	0.210		−3.72	0.3540
11	Fastened	Hex	Conical	80		0.063	0.187[a]		−2.34	0.1257
12	Fastened	Hex	Spherical	60		0.500	0.187		−4.46	0.8111
13	Fastened	Square	Flat	60		0.500	0.187[a]		−5.48	0.9460
14	Fastened	Square	Conical	90		0.125	0.187		−3.54	0.4702
15	Fastened	Square	Spherical	80		0.063	0.210		−1.95	0.4702
16	Fastened	Hex[a]	Flat	90		0.063	0.187		−2.66	0.1223
17	Fastened	Hex[a]	Conical	80		0.500	0.210		−7.66	0.9668
18	Fastened	Hex[a]	Spherical	60		0.125	0.187[a]		−2.30	0.4471
Average									−5.59	0.4760

[a] Dummy treated.