PERFORMANCE ASSESSMENT OF CONTROL LOOPS – CASE STUDIES

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Abstract: This paper presents some case studies about the use of control loop performance assessment tools and techniques. Many loops from different industrial segments have been studied and presented a good potential for optimization. The audit of these loops revealed high variability and oscillation problems due to improper loop tuning, valve problems and wrong control strategy implementation. Many control loop automatic assessment indexes will be discussed. The paper will emphasize that these tools and techniques can be applied to a wide range of common industrial control loops, which can contribute to increase its performance and therefore improve enterprise KPIs.

Keywords: Control Loop, Oscillation, Performance Analysis, PID Control, Process Control, KPI.

1. INTRODUCTION

Great effort has been done on the modernization of industrial plants. New control equipment, such as PLCs, DCSs, networks, intelligent devices and machines have been installed together with new software tools. The implementation of these assets has required great investment and the results obtained were also great. However, the performance of these assets has a natural tendency to decline as a consequence of process changes and equipment wear. Therefore, new tools for Performance Supervision have emerged as a solution for continuous monitoring and optimization of these assets. One key asset today is the control loop.

As the plants were operating continuously driven by automatic control devices and there was no dedicated software to assess the control loops, few efforts have been taken to optimize these loops. As a result, there is a great potential for optimization in regulatory control. Control loop auditing on 700 control loops from 12 different Brazilian companies (Petrochemical, Pulp and Paper, Cement, Chemical, Steel and Mining segments) from July/2004 to October/2005 showed in average that:

- 14% of loops showed excessive valve wear
- 15% of valves showed problems with stiction and hysteresis
- 16% of loops were in manual mode
- 16% of loops had severe tuning problems
- 24% of loop's controller outputs were saturated most of the time
- 41% of loops oscillated due to tuning problems, coupling, disturbances and actuator problem

The statistics are alarming, although they are better than those presented in Ruel (2003) for North-America statistics. However, the availability of automatic control loop performance assessment and diagnosis tools for control loop auditing has opened new opportunities for industrial plants. It is already possible to automatically find the biggest payback loops between thousand of loops plant-wide, have automatic diagnosis of the causes for its bad performance and have all the tools to optimize and keep a good performance. These tools are based on a set of indexes for control loop performance assessment, and they are very helpful to reach the optimum performance of the process according to Operational Excellence.

Harris (1989) proposed a new index that compares the controller error variance with the results that can be realized by a minimum variance controller. Using this index, it is possible to know if the loop is performing well or not regarding its error variance. Thornhill, *et al.* (1999) discussed the use of CLPA (Control Loop Performance Assessment) algorithm based mainly on the work of Harris (1989) for refinery-wide control loop. They presented some guidelines to correctly adjust the configuration parameters and interpret its results. Thornhill and Hägglund (1997) showed the integration between CLPA and oscillation detection. The goal was to detect and diagnose the cause of oscillation in control loops which can be a tuning, hardware or disturbance problem. Thornhill, *et al.* (2003) also presented an oscillation detection method based on the regularity of the zero crossings of filtered autocovariance function. By using this method it is possible to find coincident oscillation periods plant-wide and its spectral power. Analyzing these results, it is possible to prioritize the most important oscillation periods and audit the loops in order to remove the oscillations and therefore reduce control loop variability. Integrating process control KPIs (Key Performance Indicators) with Enterprise KPIs (Gerry and Buckbee, 2005) it is them possible to increase the company performance in terms of profits, quality, total costs, throughput, uptime and operating costs.

This paper will present the benefits of using a complete software tool for Control Loop Performance Assessment and Diagnosis on the auditing of industrial control loops. This tool assesses continuously all plant loops, prioritizes the worst performing loops and pin-points its problems. On *Section 2*, many real case examples will be shown to validate the usage of this tool and present the excellent results that can be obtained by control loop auditing. *Section 2.1* illustrates oscillation-by-valve detection and *Section 2.2* shows oscillation-by-tuning detection. *Section 2.3* deals with cascaded loop tuning and *Section 2.4* shows the benefits of variability reduction. *Section 2.5* talks about root causes detection of a problem. Finally, *Section 3* presents the conclusions.

2. CASE STUDIES

This chapter presents some practical cases that illustrate some common problems with PID control loops and how these problems could be solved using control loop performance assessment software. These cases took place on several companies from different market segments. Therefore, each one achieved different results, but always related to quality improvement, cost reduction and productivity increasing.

2.1 Detecting actuator problems

In a petrochemical plant, 100 loops were being monitored by performance supervision system. The software automatically identified the presence of oscillation, assigning 99.93% to the *Oscillating* index and 93.54% to Osc. Valve index, as can be seen on Fig. 1. Each index is scaled on a 0 to 100% basis, with 100% being fully confident of the diagnosis. In this case the software diagnosed the presence of oscillation caused by a valve problem. To validate the software diagnosis, a stiction and hysteresis test was performed as can be seen on Fig. 2, and the software quantified 2.1% of stiction and 0.06% of hysteresis. As the valve stiction was excessive, the maintenance team decided to inspect it. They moved the valve along its entire course for some times trying to eliminate or reduce the stiction effect. The result was a reduction in stiction that was sufficient to eliminate the oscillation as shown on Fig. 3. On this figure we can see the *Osc Valve* assessment trend going down from 100% to almost 0% after the maintenance intervention.

This example illustrates that automatic oscillation detection can be a valuable tool for predictive maintenance. It is possible to know which valves have problems and also measure it with no need to remove the valve. It is particularly important when we have a large number of loops to monitor. For instance, it is possible to know which valves need maintenance before a shut down. Combining the information of this index with other indexes that can measure the valve activity (valve travel and valve reversals, i. e.) it is possible to have a precise list of valves that really deserves maintenance, in order to decrease plant shutdown time.

Loop name	Description	SP changes	Oscillating	Osc - Tuning	Osc - Load	Osc - Valve
Sort	Sort	Sort	Sort	Sort	Sort	Sort
101FIC009	RAMAL B	3359	100	0.0001042	6.944e-6	99.93
101PIC079	101V1 A/B	1.678	100	6.993e-6	0.8394	98.81
101FIC008	RAMAL A	2809	100	0.7641	2.083e-5	98.4
101FIC218	REFLX 101	2888	99.93	9.722e-5	0.5558	93.54
101FIC401	GLP-2 TQ	360	100	0.001	0	80
101FIC107	PASSO2 101F1	2648	100	5.556e-5	4.653	75.21
101PIC352	101-V-4	12.83	95.9	4.861e-5	0.6252	70.21

Fig. 1. Oscillation detection on a flow loop

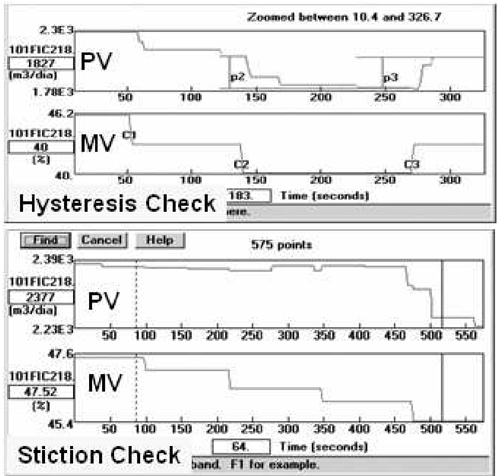

Fig. 2. Hysteresis and stiction tests

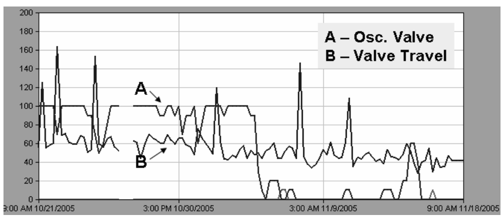

Fig. 3. Oscillation due to valve index reduces from 100% to almost 0% after maintenance as well as valve travel index.

2.2 Reducing energy costs

High variability often causes waste of energy. Fig. 4 shows an example in a cement plant. A temperature control loop whose setpoint was 120ºC, was presenting oscillations with 60ºC amplitude. This loop heats the oil for two furnaces and presented oscillations due to aggressive tuning. The correct tuning of this loop decreased its variability and also reduced the signal to the inductive heater. According to the cement plant professionals, the elimination of these oscillations resulted in an energy consumption reduction from 45kWh to 25kWh for the heater. This represents an economy of about US$ 8,000.00/year for this loop. It is important to emphasize as well that the variability reduction also guarantees more stability for this process, what can reduce unexpected shutdowns.

2.3 Detecting and correcting oscillations due to tuning

In a petrochemical plant, a flow loop from a distillation column presented oscillation due to tuning according to automatic diagnostic from performance assessment software (Fig. 5).

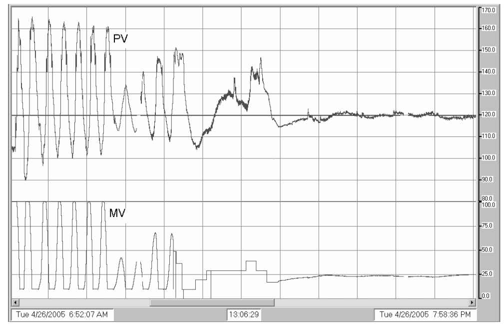

Fig. 4. Tuning decreases variability and valve travel in a temperature loop

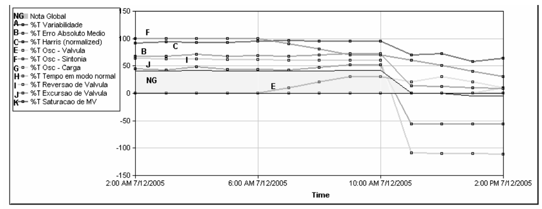

Fig. 5. Assessments indexes for a flow loop in a distillation column

As the software monitors the loop continuously, if the operator changes the setpoint or change the controller output with the loop in manual, the software automatically finds a model and tuning parameters for the loop. Fig. 6 presents the identified model and Fig. 7 presents the simulation of the old tuning parameters (Kp=0.4 and Ki=1.25 rep/min) and the proposed tuning parameters (Kp=0.11 and Ki=2 rep/min). The proposed tuning is more conservative, what can be confirmed at the robustness plot of Fig. 8. This is a plot which shows how robust a closed loop is with the PID parameters proposed. The cross and the trapezoid in the plot delimits the safety region in such a way that: if the curve is on the right side of the trapezoid, the closed loop is stable; if the curve is on the left side of the trapezoid, the closed loop is unstable; and if the curve is inside the trapezoid the loop oscillates.

Identified Process Model

$$\frac{e^{-3s}}{0.3 + 0.68s} \text{ seconds}$$

Gain	3.3	
Dead time	3	seconds
Time constant	2.3	seconds

Fig. 6. Flow loop identified model

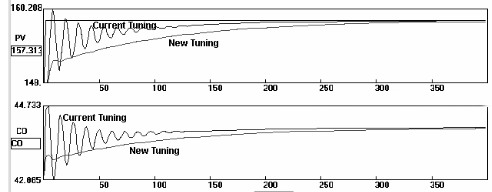

Fig. 7. Simulation of current and new tunings for distillation column flow loop

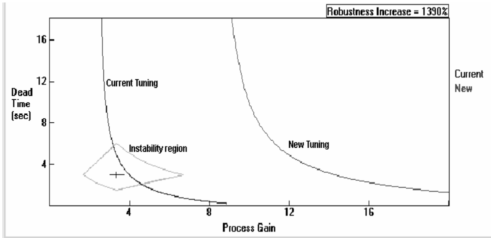

Fig. 8. Flow loop robustness plot

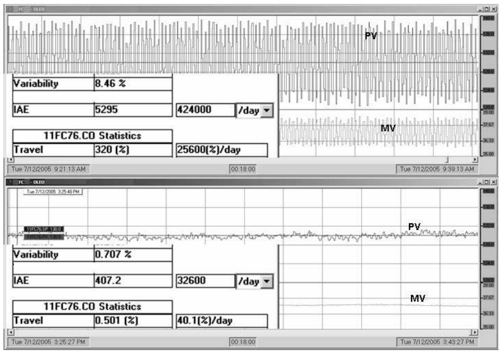

Fig. 9. Variability reduction on flow loop

Therefore, the new tuning parameters are far from the unstable region which guarantees robust tuning parameters. Applying the proposed tuning loop variability was greatly reduced as showed on Fig. 9. The oscillation detection index also reduced as showed on Fig. 5.

2.4 Adjusting the response time of cascade loops

This case illustrates cascade tuning of a tray level and flow loops on a refinery distillation column. Those loops were chosen to be optimized because they presented the worst performance assessments including excessive valve movement (Valve Travel), high Avg Absolute Error and saturation of the controller output (Output at limit). Therefore, tuning software has been used to model and tune both loops. Fig. 10 shows that after tuning the loops, many indexes for these loops reduced as well as its global performance assessment (Avg % to threshold). The smaller the index the better the loop performance is as we will be much closer to the configured baselines for the loop indexes. Fig. 11 shows a trend chart of the master loop indicating the great variability and IAE decreasing.

Using tuning tools integrated with the performance supervision software it was easy to detect that the old tuning parameters made the master loop faster than the slave loop. This can be measured by the RRT (relative response time) index (Fig. 12). It is a good practice to have the slave loop at least three times faster than the master loop. As found, this was not the case. After tuning, the slave loop became much faster than the master loop, which greatly improved the performance of this system.

	Avg % to threshold	%T Avg abs error	%T Osc - Valve	%T Osc - Tuning	%T Variance	%T Valve travel	%T Output at limit
17/11	44.1	185.9%	0.0%	0.0%	44.7%	206.4%	15.5%
18/11	15.86	61.3%	0.0%	0.0%	11.0%	75.8%	1.3%
19/11	10.48	25.5%	0.0%	0.0%	1.9%	33.3%	0.0%
20/11	5.313	10.8%	0.0%	0.0%	0.2%	20.8%	0.0%

Fig. 10. Level loop performance assessment indexes

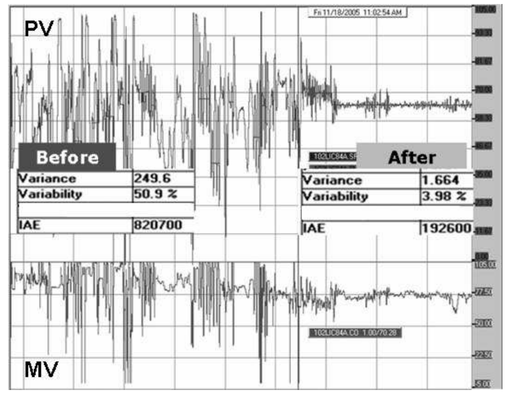

Fig. 11. Level loop variability decrease

Loop	Parameters	Before tuning	After tuning
FIC001 Slave Loop	Kp	0,25	1,1
	Ki (rep/min)	0,25	2,7
	RRT (s)	1000	40
LIC001 Master Loop	Kp	1	0,64
	Ki (rep/min)	0,25	0,2
	RRT (s)	760	1100

Fig. 12. Cascade loops RRT and tuning parameters

2.5 Reducing variability and changing the operating point

This case was extracted from a cement plant. It's about a pressure loop that is used to control the pressure in the extremity of a cement furnace. The objective of this loop is to maintain the pressure as close as possible to -1 mmH_2O but never reaching positive values.

This loop was chosen for auditing because, as it can be seen on Fig. 13, it was presenting the biggest A*verage Economic Assessment* comparing to the other loops. The *Average Economic Assessment* measures the performance of a loop considering a predefined set of assessments like Variability, Oscillating, Valve Travel, error and others. This global assessment also considers the economic importance of the loop. The greater the Average Economic Assessment the worst is the performance of the loop which indicates that there is a good potential for improvement.

Drilling down deeper into the performance assessment for this loop, the software also pointed out that the performance was poor due to oscillation problems on the loop.

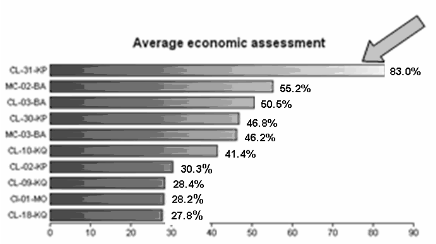

Fig. 13. Pressure loop presents the biggest average economic assessment on a cement plant

Loop name	Description	Unit operation	Oscillating	Osc - Hardware	Osc - Tuning	Osc - Load	Oscillation period 1	Oscillation period 2	Oscillation period 3
CL-22-KQ	Vazão de Ar CL-22-VE	Forno	80	0.001	0	0	303.7	148.5	99.52
CL-08-KQ	Vazão de Ar CL-08-VE	Forno	0	0	0	0	300.4	131.3	80.58
CL-31-KP	Pressão no Cabeçote	Forno	100*	100*	0	0	298.9	148.7	100.5
MC-02-BA	Coriolis primario	Forno	100*	0.001	0	0.001	294.1	149.4	64.49
CL-09-KQ	Vazão de Ar CL-09-VE	Forno	60	0.001	0	40	289.3	132.4	85.94
MC-03-BA	Coriolis secundario	Forno	0.001	0	0	0.001	443.6	71.49	196.3

Fig. 14. Coincident oscillation periods at a furnace

Inspecting the oscillation report (Fig.14), it was possible to see that the loop was oscillating with the same period as the air flow loops of this furnace. In order to improve system performance Torres (2005) proposed an optimization strategy consisting of two steps: tuning of the coupled air flow loops and, after that, tuning of the pressure loop itself. This strategy was implemented and the results can be seen on Fig. 15 and Fig. 16. The figures show a great improvement of the global performance of the loop due to a significant reduction of the variability, absolute error and valve travel.

Once the variability was reduced one question came out: Is it possible to move the setpoint towards -1 mmH2O? In fact, with a significantly smaller variability there is no need to have a security band of 5 mmH20 (SP = -6mmH2O). For instance, it is now possible to move the set point to -3mmH2O. Closer to the safety limit of -1mmH20, the plant can recycle more hot air to the process instead of disposing this air to the atmosphere, what decreases the coal consumption in the furnace. Fig. 17 illustrates this change on the operating point.

2.6 Root cause analyses

Performance supervision software has been used to analyze an ingot heating furnace of a metallurgical plant. After some time monitoring the loops, the software detected oscillation problems on almost every loop of the furnace (Fig.18).

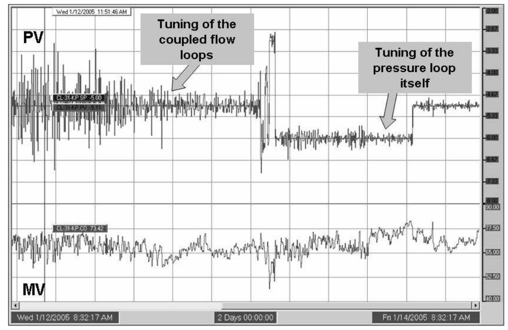

Fig. 15. Variability reduction on a pressure loop

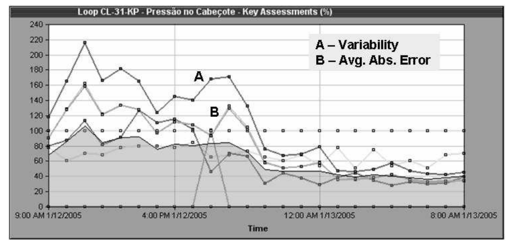

Fig. 16. Performance assessment indexes improvement after tuning the coupled loops

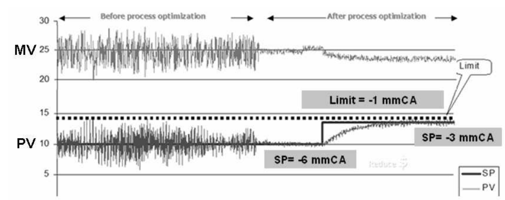

Fig. 17. Optimization due to variability reduction

In fact, according to Torres et al. (2005), in a total of 36 loops on the furnace, the software detected that 67% of the loops (24 loops) were oscillating at a period around 280 seconds (Fig. 19). Those loops were also oscillating at the same oscillation period of the PCI loops (FIC1027 and PCIC1027), which controls the calorific power of the gases used to heat the furnace. This means that, nothing could be done with the temperature loops of the furnace until the PCI loop oscillation was eliminated, because it's clear that the PCI oscillation was the root cause for all the other loops oscillating.

After the root cause was identified, it was fixed by rearranging the PCI control strategy and then all other loops stopped oscillating, making the furnace process more stable and saving on gas consumptions. Fig. 20 shows the PCI control before and after optimization. Estimative for this furnace previewed more than US$ 100.000 savings on gas usage alone.

3. CONCLUSIONS

The paper presented some general statistics for control loop auditing in many Brazilian industrial plants.

Loop name	Avg % to threshold	%T Variability	%T Avg abs error	%T Oscillating	%T Time in normal
TIC1821	65.94	82.50%	111.10%	**100.00**%	0.00%
TIC1721	60.35	40.10%	25.00%	**100.00**%	0.00%
TIC1621	62.23	79.80%	99.10%	**100.00**%	0.00%
TIC1221	70.73	84.60%	81.30%	**100.00**%	0.00%
PIC1913	97.79	107.10%	102.60%	**100.00**%	0.00%
PIC1324	71.46	74.80%	181.00%	**100.00**%	0.00%
PIC1224	107.7	108.90%	66.10%	**100.00**%	0.00%
PIC1011	40.71	24.30%	55.10%	**100.00**%	0.00%
LT1932A	126.1	128.80%	124.80%	**100.00**%	0.00%
FIC1932	134.7	no baseline	78.10%	**100.00**%	0.00%
FIC1824	45.67	no baseline	67.40%	**100.00**%	0.00%

Fig. 18. Oscillation detection on ingot heating furnace loops

Loop name	Oscillating	Oscillation period 1	Oscillation period 2	Oscillation period 3	Oscillation strength 1	Oscillation strength 2	Oscillation strength 3
FIC1722	100	**269.4**	142.9	708.5	35.24	19.72	12.89
FIC1624	100	753.8	**268.8**	160	41.5	18.97	4.434
FIC1724	100	693.1	**295.8**	187.8	25.79	16.52	12.51
FIC1822	100	**277.9**	146.8	93.08	38.68	14.12	10.9
FIC1622	100	746.6	**256.9**	148.9	39.53	26.44	5.987
FIC1522	90	**257.3**	753.8	151.2	29.67	28.14	12.91
TIC1521	70	801.3	**294.7**	189	55.04	28.06	6.936
PIC1324	100	**272.5**	147.3	103	46.56	21.87	13.98
FIC1027	100	**280.5**	148.6	543.2	88.06	6.184	2.52
PCIC1027	100	**277.7**	148.3	108.8	80.18	10.62	4.493

Fig. 19. Coincident oscillation periods

These statistics revealed that process and control engineers have not being able to work on control loop optimization in the past few years in the great majority of these industries. The main reason for that was the lack of Control Loop Performance Assessment tools for supporting engineers to work on the loops in the plant. Therefore, there is a true potential for great improvement in regulatory control that can bring a very good payback for these plants.

Many easily-interpreted assessments or control indexes have been discussed through real industrial examples. These indexes can be calculated continuously by the use of dedicated performance supervision software. It is possible to simultaneously analyze thousands of control loops and generate KPIs for maintenance, production and quality teams. This can increase the productivity of maintenance and process engineers. By using software tools for continuous performance assessment in the RPM (Real Time Performance Management) sense, engineers can spend their time on focusing to solve the problems pointed out by the software. This is a very important issue to improve plant performance and to sustain the results according to Operational Excellence.

It is important to emphasize that not only the use of dedicated software is enough to optimize control loops. Well trained people and continuous optimization cycles are needed as well. The optimization of control loops is not a job to be performed on demand. There should be a change in

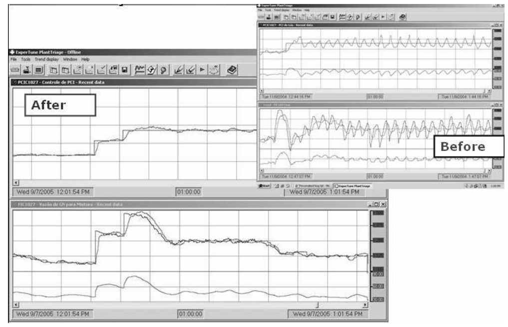

Fig. 20. Changes in PCI control remove oscillations

the way the corporation maintains and keep track of regulatory control KPIs.

It has been repeatedly demonstrated that these optimization efforts yield direct economic benefits. Indirect benefits of smoother operation, reduced maintenance, and improved product quality are harder to quantify, but add significantly to these benefits. These benefits cannot be maintained without some level of continuous performance supervision. Therefore, the optimization process should be a continuous effort. The combination of tools, analysis, corrective actions and benchmarking can then move the company efficiency to a higher level.

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