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SPC AND INJECTION MOLDING

INTRODUCTION

This paper is based on a study at the "Raviv" injection molding factory. This plant is now QS9000/ISO 9001 certified and works as a sub-contractor mainly in the automotive and electrical field. The aim was to define those parameters of the injection process which would be most useful for monitoring with SPC and thus reduce the need for post injection tests. As is known one of the main problem with precision injecting is the time taken for parts to acclimatize and reach their final dimensions. The need for on-line checking is vital to prevent hours of work being rejected.
The study was written in 1992

QUALITY

"In the beginning God created......he saw all that he had created and it was good." (Genesis) Despite what should have been perfect planning and execution it was necessary to reject all mankind (apart from Noah). It is hard to say if the planning and execution were better the second time or the customer's requirements were less. Customer requirement is the driving force in today's world. Increased operational quality reduces costs in the long run by eliminating costly rework. The basic trilogy of quality is planning, control and improvement (1). The experiment was designed to increase the control phase and thus encourage improvement. This is despite the fact that 75% of the problems are caused before the tool reaches the machine (2). SPC (Statistical Process Control) is a growing demand by customers on physical properties thus the logical step is to use SPC on the process itself, isolate the parameters to monitor and thus predict problems in advance, saving scrap and rework.

SPC AND INJECTION MOLDING

The injection process is one of complexity with many parameters of temperature, pressure and time combining dynamically to produce a complete system. The problem is to identify the parameters which will give the clearest indication of potential problems. These parameters can be divided into several groupings:

1) Machine; Parameters such as back pressure, rotational speed of the screw, heater bands. These are the set by the operator and are not subject to random variance thus are not useful for SPC.

2) Process; Values that are produced as a result of the above parameters, injection or plastification time, cushion or total cycle time. These values are a result of the changes in the machine or the environment and are valid for SPC.

3) Product; This returns us to the original dilemma of checking the part and not the process. It has been shown that there is a connection between weight and measurements thus this was used as a control. (3,4)

4) Peripheral equipment; This is a valid source of data for SPC. (5)

THE EXPERIMENT

The experiment was run on standard injection molding machines in current use at the Raviv plant, Arburg and Kloekner Ferromatik with a clamping force of between 400 kN and 3500 kN and computer control. Current production runs were chosen without any special attempt to optimize conditions. The parts were weighed to an accuracy of 0.01g and the following parameters collected: Cycle, Injection, and Plastification times, Injection and Holding pressures as well as the cushion.

Seven separate machines were tested using materials including PA 66 (with and without glass fibers) POM, ABS and PP and at least 100 samples were taken in groups of five from each machine.

Control charts were drawn by the normal SPC methods both for groups of Injection, and Plastification times, Injection and Holding pressures as well as the cushion. Seven separate machines were tested using materials including PA 66 (with and without glass fibers) POM, ABS and PP and at least 100 samples were taken in groups of five from each machine. Control charts were drawn by the normal SPC methods both for groups of five further credence to the use of individual charts.

RESULTS

The resulting charts were analyzed to find correlation between the parameters of the machine and the weight. They were further examined as to their usefulness as a tool for predicting trends.

It was seen that no real correlation could be found between the parameters and the weight and what was more disturbing the control limits were so narrow that most of the charts showed processes out of control. These control limits in some cases were so narrow as to be meaningless, for example, Injection time in one chart was within control limits only 0.006 s wide. The machine can only measure in hundredths of a second, this value is therefore of no practical significance. The control limits in the individual charts are slightly wider but still fail to provide meaningful results. The Table gives some examples (all results show one order smaller than the capability of the machine to measure). The columns UCLx-LCLx and %X show the width of the control charts and that width as a percentage of the mean. Control Limits of selected parameters

GROUPS of FIVE

.	X	R	UCLx	LCLx	UCLx-LCLx	%X
Injection time (s)	0.264	0.006	0.267	0.261	0.006	2.41%
Cycle time (s)	18.72	0.18	18.82	18.61	0.21	0.57%
Plastification (s)	4.40	0.18	4.50	4.30	0.20	4.59%
Cushion (mm)	9.04	0.19	9.15	8.93	0.22	1.21%
Weight (g)	34.306	0.015	34.314	34.297	0.017	0.03%

Individuals

	X	R	UCLx	LCLx	UCLx-LCLx	%X
Injection time (s)	0.264	0.003	0.272	0.256	0.015	5.76%
Cycle time (s)	18.72	0.10	18.98	18.46	0.53	2.81%
Plastification (s)	4.40	0.08	4.61	4.19	0.26	9.75%
Cushion (mm)	9.04	0.09	9.27	8.81	0.47	5.16%
Weight (g)	34.306	0.007	34.325	34.286	0.039	0.11%

As can been seen the weight is remarkable stable with a control width of 0.11% of the mean in the individual charts. Individual charts because of the small sample size give larger control limits but a reduced range. Despite the consistency of the results , or because of them , all the parameters show that the processes are out of control.

REGRESSION ANALYSIS

Due to these results which are useless in a conventional SPC monitoring system, either as operator drawn charts, on-line computer drawn charts or as a basis for tolerances that can be entered into the press, an attempt was made to use regression analysis. First the coefficient of correlation was obtained for the parameters in respect to the weight, as individual results, and as averages of the parameters representing the different weights.

Coefficient of Regression

.	Injection T.	Cycle T.	Cushion	Plastification T.	Groups
Averages					
1-100	-0.319	-0.367	-0.634	<u>-0.891</u>	6
101-200	<u>-0.861</u>	-0.681	-0.644	<u>0.925</u>	23
1-200	-0.307	-0.479	-0.648	<u>-0.887</u>	23
Individual					
1-100	-0.411	-0.241	-0.394	-0.086	100
101-200	-0.001	-0.077	-0.150	0.485	100

It can be seen that the only parameter that shows a consistent pattern of correlation is that of plastification time. The correlation only exist in the groups of averages and not in the individual results, this is probably due to the reduction of groups. this reduction also is the cause of the positive correlation in the results 101-200 where there are only 6 different weights as opposed to 23 in results 1-100.

With this correlation established it is possible to calculate the equation of regression and use this as a basis for control. The equation for the plastification in respect to the weight is:

$$Y = -0.142 X + 34.906$$

Given that the mean weight is 34.35, with tolerances of ±0.1g, this equation gives us tolerances for plastification of 3.21s-4.62s . These tolerances are far more useful than the control limits of the SPC and can be entered into the injection press, to give on-line control.

The fact that the plastification time showed a correlation is not surprising as this parameter gives an indication of the state of the melt and uniformity of the raw material.

DISCUSSION

The project which started as an attempt to show the importance of SPC in the control of the machines and to show the ease of using a well tried quality assurance tool in the plant failed. The major problem with SPC is that it was designed for metal workshops where the machinery is far more primitive than in injection molding. The interaction of parameters in molding is such that it is very difficult to build a definite model. A further problem is that SPC cannot deal with no change, this means that a parameter that does not change will be by definition out of control, an absurd situation. The mathematics of SPC can also cause the manufacturer that works within very close tolerances to be penalized. 20 sub-groups of 5 products were weighed , whilst the difference between the parts varied overall by 0.02 g (a part of 9.43 g), there were 2 groups out of control. This can cause rejection of parts. The demands of customers for the use of SPC are likely to cause producers to work between larger tolerances than they are capable, to prevent rejects of good parts.

SPC on the parts is useful, because of the nature of polymers the dimensions can not be immediately checked. The weight as an indicator of part size can thus be used. Here again it should not be used blindly but as an indicator of trends. SPC on the weight can certainly show flash or short shots that might escape the naked eye. The control charts should not be used as the sole criteria for scraping parts, rather to ring a warning bell.

It has been shown that the use of SPC on the machines themselves is limited. The narrow control limits and the complexity of isolating parameters makes each attempt a shot in the dark. The introduction of closed loop machines means that the self correction of the machines renders the control charts meaningless. In discussions with molding machine manufactures they admit that the trend to produce SPC software is a customer demand that they do not fully agree with. " It should be discussed with the automobile manufacturers and the molding factories if it is appropriate to transfer SPC defined for metal shaping to injection molding." (6). One manufacture told me of customers that bought a computerized machine just for the protocol. The continuous monitoring of computerized machines puts in question the sampling system of SPC. The computer can monitor each and every cycle for the same cost, tolerances of the parameters based on regression analysis or experience will be far more effective. The control limits that we have seen above will not allow the machine to function normally.

There are other factors apart from the presses (the classic target for SPC), that affect the quality of the injection. These factors are much more easily controlled and monitored.

1) Material: The homogeneity of the mixture that is feed to the machine, its dryness (a good subject for SPC) , and its initial quality.

2) Temperature of the tool: The temperature of the mold can be critical. It has been shown that in a specific product 81% of dimensional changes are due to mold temperature. (7) Generally molders set the controllers of their mold heaters to a temperature, maybe check the mold after set-up and then leave it. The change in temperature in the shop between day and night can be seen on products clearly. The importance of increasing control on mold temperature can not be underestimated.

3) Melt temperature: Control on this parameter is vital. To often it is not known, modern machines have thermocouples to measure this temperature which is a product of the heater bands and the shear in the cylinder. The value of this parameter is that it can give a broad picture of the functioning of several systems at once, it is also crucial in certain materials which have a very narrow processing window.

4) In cavity pressure: This is generally accepted as the best basis for the V-P changeover. This gives another external point to control as well as providing the operator with a far more scientific base for his conditions.

5) Optimization of conditions: This is a complex process which can take a long time. Crystalline materials that can take at least 24 hours to reach dimensional stability means that after each adjustment it is necessary to wait.

CONCLUSIONS

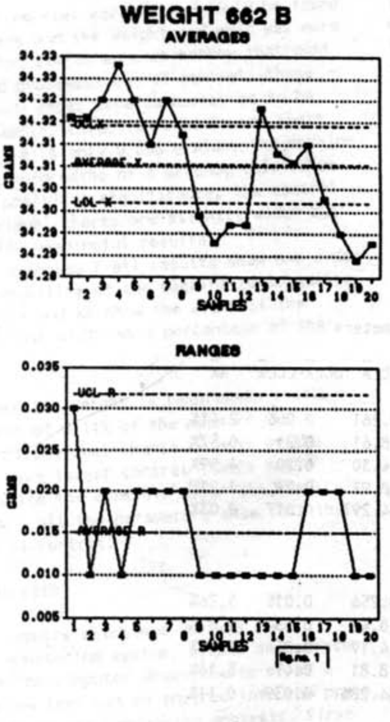
1) SPC. The possibility to control the product through SPC on the machine is very limited. If it is desired to produce SPC control charts it is only worthwhile to use one or two parameters, typically, cycle and plastification times. These will give an overall impression of the machines capabilities. It is worthwhile to control the weight by SPC, not as a rejection tool but as a easily available check on the part.

2) Regression analysis : This is an interesting tool that needs to be developed. The results here give a possibility for building a useful method for stating tolerances.

3) Other tools. The use of thermocouples and pressure transducers in the molds is recommended. The control of the temperature of the mold is vital to quality injection. This control is especially essential in regions with large temperature changes between day and night or between seasons. The use of thermocouples in the nozzle area of the cylinder is also vital to monitor the actual melt temperature and thus not be dependent on measurements of the temperature of the cylinder.

4) Quality environment. This is perhaps the most important factor of all. Management must work to produce an atmosphere were workers are aware of the importance of " right first time ". This can only come with the drive and determination of senior management who have a real commitment to quality. The ISO 9000 qualifying procedures in this instance give a tremendous boost to the company in terms of making the whole team aware and responsible for its actions. Demming's 14 points look good on paper but they look even better when you are part of their application

DIAGRAMS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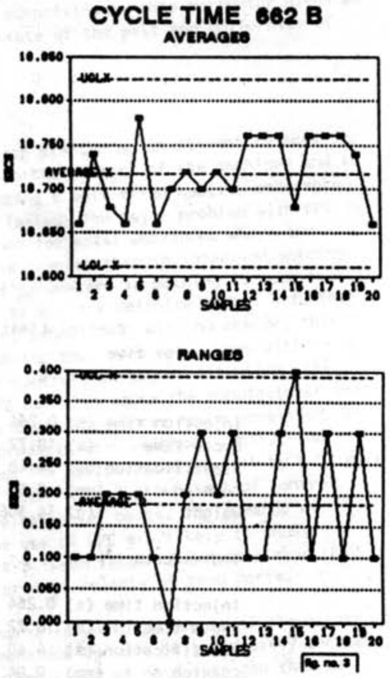
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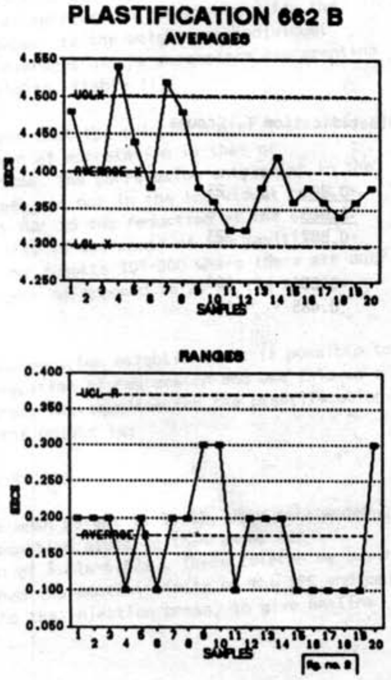
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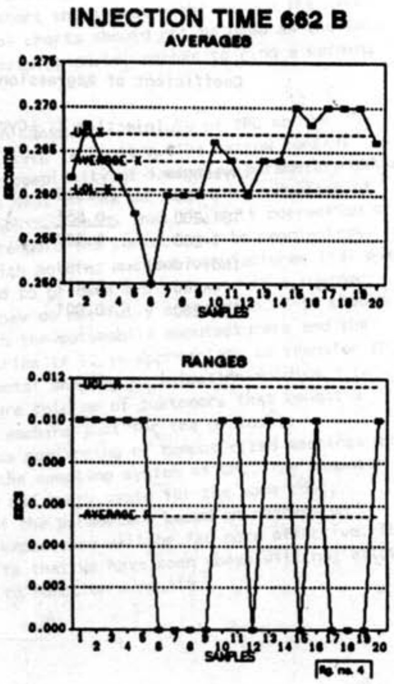
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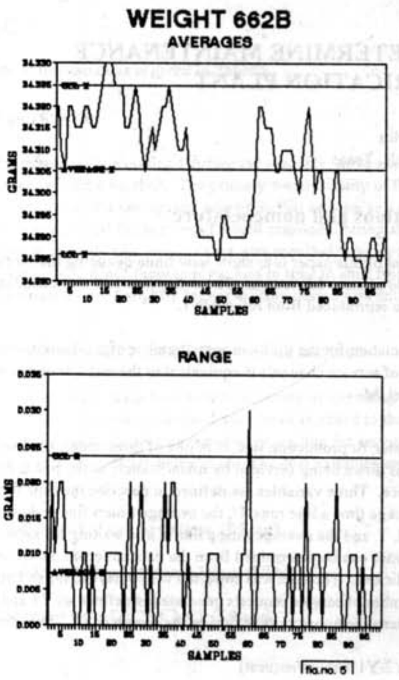

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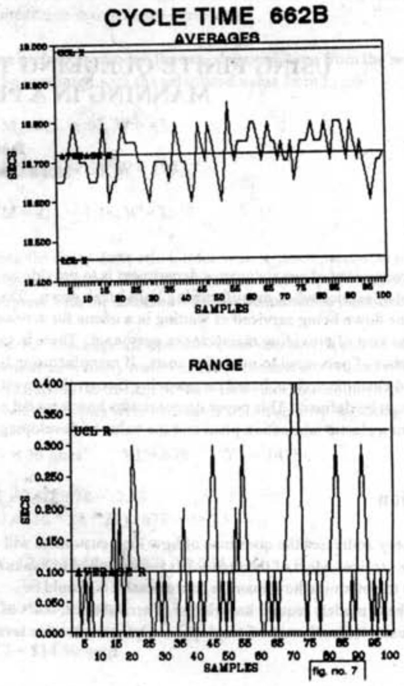

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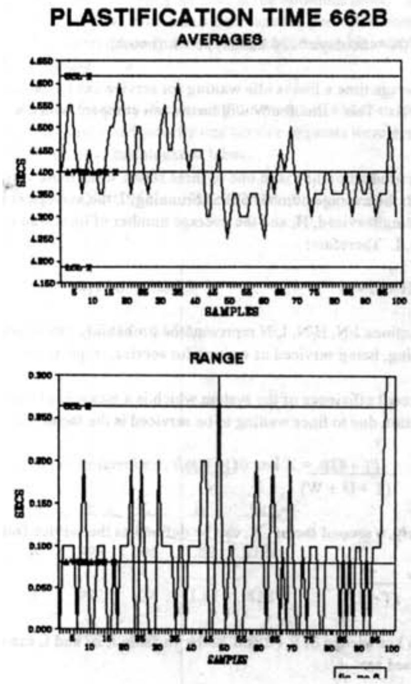

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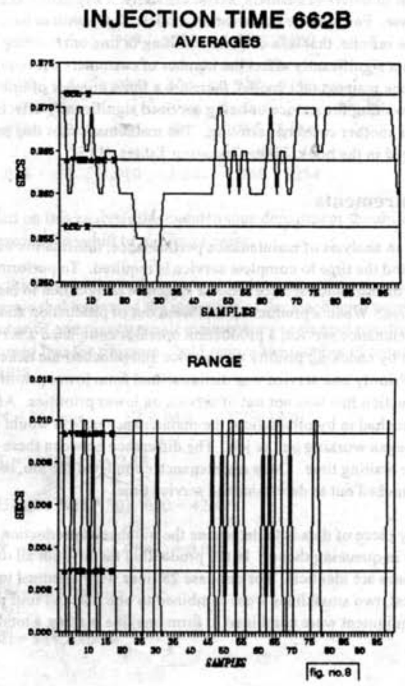

fig. no.8

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