Implementing SPC in the Materials Control Lab

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As an important fabricator of precision molded rubber products, we had always understood that effective quality control depends on determination, hard work and the appropriate use of state-of-the-art technology.

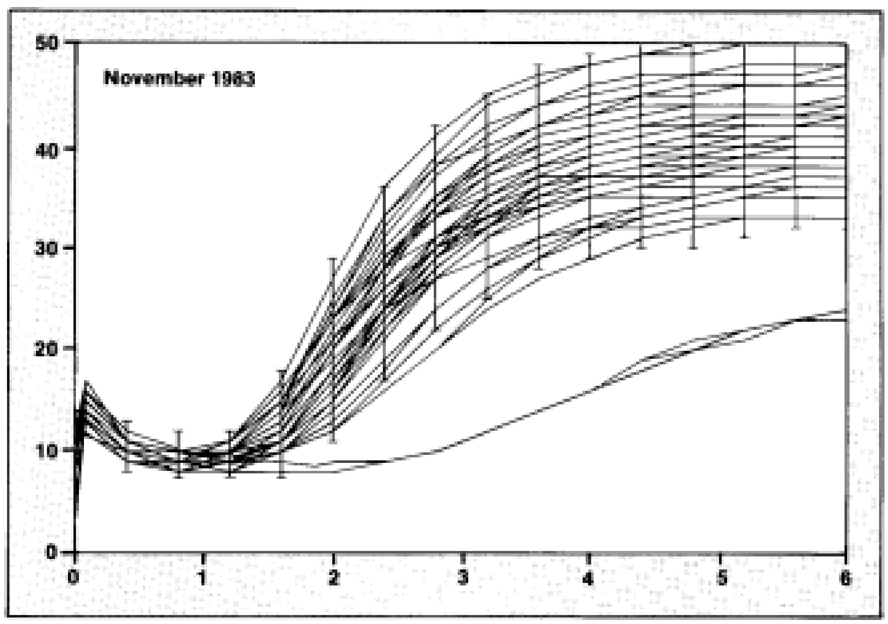

Fig. 1 — Rheology curves for compound 7013, a 70-durometer, nitrile oil-resistant compound.

By 1983, at Seals Eastern we realized that increasingly rigorous quality expectations on the part of our customers demanded that quality control become an integral, ongoing part of the manufacturing process. In fact, we concluded that quality control standards must to an important degree actually regulate the manufacturing process in a continuous feedback loop. Thus, in this model, achieving quality control becomes and active, prospective process, rather than the passive, retrospective activity it once was.

Statistical process control was the chosen vehicle for upgrading quality control at Seals Eastern. But would it be feasible, or even possi ble, to apply SPC to defining and maintaining acceptance criteria for mixed production batches? How could we put statistics to work in setting control limits on tensile strength, hardness, curing characteristics, specific gravity, compression set, and the like?

Since rheology is our principal tool for maintaining quality control of production batches, we decided to apply process capability and control chart procedures to our Rheo meter 100 output data. But from past experience, we knew that doing this would be a staggering task, involving the ongoing recording and analysis of at least six and possibly as many as 10 points along the rheometer curve, including, of course, ML, TS2, and TC90. This meant recording data points on each of six to 10 control charts for each of the several dozen high-volume production compounds Seals Eastern regularly mixes.

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Obviously, we couldn't do the job without a computer. What's more, we needed a computer with graphics capability and statistical software with extensive archiving capability. In 1983, this sounded like $100,000 plus investment. Our existing "1970's minicomputer" was good at number crunching but had no `graphics capability.

A major problem was just how to put rheology data into a computer. Should we manually input digitized rheometer curves? Should we try and get help from Monsanto Instruments & Equipment Co., manufacturer of the Rheometer 100? Or should we find someone to digitize the analog output of the Rheometer?

Our solution? To utilize the innovative work of program designer Paul Hertzler and the manifold capabilities of the Hewlett-Packard HP86 Microcomputer. Paul had already created analog/digital interface between the Rheometer 100 and the HP 86B. Perhaps more importantly, he had created software which made it possible to use this interface in the statistical analysis of 16 points along the rheometer curve in addition to ML, TS2, and TC90.

The Hertzler system, known as "RheoLogic," is now commercially available. It is designed to:

- Acquire Rheometer curve data electronically and store it in a disc data base, using sophisticated indexes for speed and flexibility in retrieval.

Analyze stored data using control charts and histograms. Test records can be selected for variable time periods, individual batch mixers and particular work shifts.

- Establish "normal" control limits (gates) for given compounds and permit overlaying of these control gates onto individual Rheometer test results in order to facilitate immediate QC acceptance decisions.
- Use the control gates to monitor all future production and to identify individual "out-of-control" batches, along with the reasons for the out-of-control conditions.
- Provide for statistical analysis of rheology values and physical property test results (such as tensile strength, elongation, modulus, hardness, specific gravity, mooney viscosity, compression set) using control charts and histograms.
- Provide for redraw of individual rheometer curve groupings.

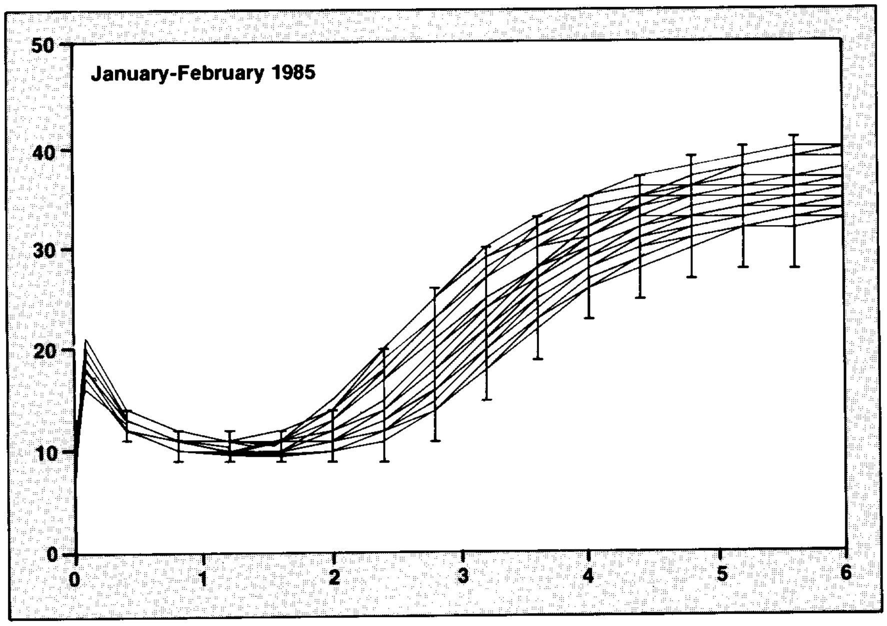

Fig. 2 — Rheology data for all batches of compound 7013 mixed in January & February 1985.

Most important, RheoLogic gives solid statistical backing for material control limits and the Material Control Lab Q-C acceptance decisions which flow from them. The system yields these benefits in seconds (compared to weeks or months were the work done by "hand") at a capital cost of $18 to $20 thousand.

Seals Eastern began using RheoLogic early in November 1983. Fig. 1 is typical of the rheology data we were generating from production batches at that time. It shows the first 40 batches of compound 7013 tested in the six minute time frame. Prior to installation of RheoLogic, we had employed 12minute testing of 7013, but switched to the six minute test in order to analyze the most active portion of curve more effectively.

Fig. 2 shows rheology data for all batches of compound 7013 mixed in January and February 1985, more than a year after the installation of RheoLogic. Compared to the 1983 results, the slope of the 1985 cure curve is generally lower and bun dles of curves are markedly tighter. This result is typical of most production compounds produced during our first full year with RheoLogic.

Ultimately it is people, not computers or statistics, which control the quality of manufactured goods. Behind the quality improvements evident in our "before and after" rheology curves are salutary behavioral changes on the production floor - greater care on the part of batch mixers in using prescribed quantities of compound ingredients. In particular, the process control approach to batch formulation has helped convince mixers that adding a bit more of this or that ingredient for good measure (the "better too much than too little" syndrome) does not, in fact, insure a better product.

Despite the success of RheoLogic in improving batch quality, naturally, we still make mistakes. when a given batch falls outside the control limits, the computer generates an "Out of Spec" record of the batch test in question (Fig. 3).

All the rheometer curves (except Fig. 3) reproduced in this article are regenerated from RheoLogic plot data. The somewhat angular segments in the redrawn curves occur because the data used for redrawing is rounded off to the nearest inch/ pound when stored in the computer

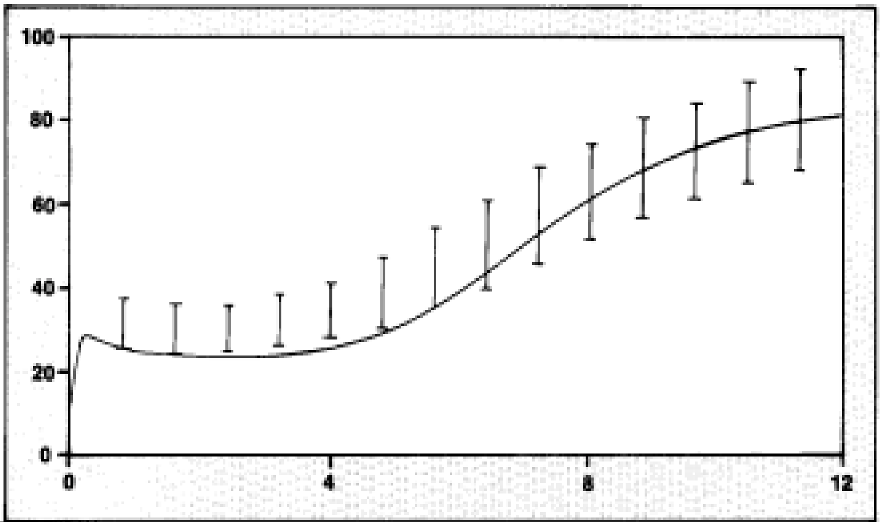

Fig 3

Fig 3 – “Out of spec” Rheology plot

disc files. In addition, all curve segments between the gates are reconstructed as straight lines.

In contrast, the Fig. 3 curve reflects the original test, and appears to be continuous because readings were taken once per second.

The gates for Fig. 1 were derived through control chart refinements of the compound 7013 statistics shown in Tables I and II. These statistics were used to produce the typical control charts for TC90 and Gates 10 and 16 (not illustrated). All three charts show marginal deviations from control limits in batches 26, 28 and 32. RheoLogic permits manual exclusion of such marginal outliers to enhance the gate selection process. As noted, the establishment of control gates, is one of the principal uses of the control chart and histogram capabilities of RheoLogic. Using only 40 production batches, initially, we were able to create a reasonable set of control gates for compound 7013 by selecting the 32 most statistically normal rheometer curves. These control gates begin the process of defining "final" control gates, reflecting the final nature of the particular mixing process.

As I've already suggested, the really important, bottom-line impact of statistical process control occurs when production people start to react to "out of control test results by altering what they do. Fig. 4 shows curves for 60 batches of compound 7013 selected at uniform intervals from over 800 batches of the material produced during a five month period in late 1983 and early 1984. Without altering the initially established gates, we have re-plotted the data to demonstrate the improvement in control which typically occurs in response to the use of process control limits or gates. It is apparent that within three months of establishing the initial gates, the rheometer curves for compound 7013 began to take a distinct downward trend. TC90 was gradually being reduced. A comparable control chart (not illustrated) indicated that TSB was on steady upward trend, indicating more careful weighing of ingredients, particularly sulfur and the sulfur donor.

These improvements occurred despite the fact that no overt attempt to train production mixing operators in the logic of control gates. This was a decision dictated by the logistical challenge of incorporating statistical process control into all aspects of the manufacturing process. We felt that the training effort had to be a comprehensive one applying to virtually everyone in the company, started with the quality control staff and then moving on to management, engineering and line supervision and finally, production.

We found that this natural response to RheoLogic generated data continued unabated and we, the Quality Control Department, were careful to avoid exerting any pressure on the Production Department apart from tightening control gates in response to accumulating statistical information and rejecting out of-control batches.

Thus, essentially all we did was to transmit objective quality control data to Production, which, in turn, conveyed it to individuals on the floor. There was no implicit or explicit coercion; it simply wasn't necessary. The experience has reminded us that people usually respond much better when they're shown how they can improve their performance rather than how poorly they are doing.

As indicated, other physical properties are also stored in Rheologic's data base and are available for rapid statistical analysis. The program permits complete analysis of ultimate tensile strength, 100 percent modulus, 300 percent modulus,

Table I — Rheometer Test Reports: Compound 7013

Run Date: 06/01/85 Shift = All Time = 6 Range = 50 Temp. = 330 Mixer = 0 Arc = 1 Page 1

No.	Lot/Batch	OK	ML	TS2	TC90	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	83K18 004		9.1	97	226	4.0	10.0	9.0	9.0	11.0	17.0	24.0	30.0	35.0	37.0	39.0	40.0	41.0	41.0	41.0	41.0
2	83K18 005		9.5	81	210	3.0	10.0	10.0	11.0	15.0	23.0	30.0	35.0	38.0	40.0	41.0	42.0	42.0	42.0	42.0	43.0
3	83K18 006		10.0	89	216	5.0	11.0	10.0	10.0	13.0	20.0	26.0	31.0	34.0	36.0	37.0	38.0	38.0	39.0	39.0	39.0
4	83K18 007		9.5	92	230	4.0	11.0	10.0	10.0	12.0	18.0	24.0	30.0	33.0	36.0	38.0	39.0	39.0	40.0	40.0	40.0
5	83K18 008		8.3	89	220	8.0	9.0	8.0	9.0	12.0	18.0	25.0	30.0	33.0	35.0	37.0	37.0	38.0	38.0	38.0	38.0
6	83K18 009		8.5	89	224	4.0	9.0	9.0	9.0	12.0	18.0	25.0	30.0	33.0	36.0	37.0	38.0	39.0	39.0	39.0	39.0
7	83K18 010		8.2	95	230	3.0	9.0	8.0	8.0	11.0	16.0	24.0	29.0	33.0	36.0	38.0	39.0	39.0	40.0	40.0	40.0
8	83K19 001		9.4	90	226	9.0	11.0	10.0	10.0	12.0	18.0	24.0	29.0	32.0	35.0	36.0	37.0	37.0	38.0	38.0	38.0
9	83K19 002		9.3	81	218	4.0	10.0	9.0	10.0	15.0	21.0	26.0	30.0	32.0	34.0	35.0	36.0	36.0	36.0	37.0	37.0
10	83K19 003		9.3	112	251	5.0	11.0	10.0	9.0	10.0	13.0	18.0	24.0	28.0	30.0	32.0	33.0	34.0	35.0	35.0	35.0

Table II — Statistics After Excluding Outliers

	Std. Dev.	Low Gate	− 3s	Min.	Mean	Max.	+ 3s	High Gate
ML	.6	7.7	7.3	8.0	9.2	10.3	11.0	10.9
TS2	12.3	64.3	55.4	70.0	92.3	127.0	129.3	114.0
TC90	29.8	186.0	144.4	198.0	233.7	320.0	323.0	259.0
G1	3.0	0.0	− 3.0	2.0	5.9	14.0	14.9	14.0
G2	.8	8.0	8.0	9.0	10.4	12.0	12.8	13.0
G3	.7	7.4	7.2	8.0	9.3	10.0	11.4	12.0
G4	.9	7.5	7.1	8.0	9.7	11.0	12.2	12.0
G5	2.3	7.4	5.5	8.0	12.3	17.0	19.2	18.0
G6	4.7	11.0	4.0	8.0	18.2	27.0	32.4	29.0
G7	6.4	17.0	5.0	9.0	24.3	36.0	43.6	36.0
G8	7.4	22.0	7.1	10.0	29.2	41.0	51.3	42.0
G9	7.7	25.0	9.6	12.0	32.7	45.0	55.8	45.0
G10	7.7	28.0	12.1	14.0	35.2	47.0	58.3	48.0
G11	7.5	29.0	14.2	16.0	36.8	48.0	59.4	49.0
G12	7.2	30.0	16.4	18.0	38.0	49.0	59.5	50.0
G13	6.9	30.0	17.9	20.0	38.6	50.0	59.3	51.0
G14	6.7	31.0	19.2	21.0	39.2	50.0	59.2	51.0
G15	6.4	32.0	20.3	23.0	39.5	50.0	58.6	51.0
G16	6.4	32.0	20.3	23.0	39.6	50.0	58.9	51.0

ultimate elongation, specific gravity, hardness, viscosity, scorch and compression set. This data may also be used as necessary in establishing acceptance.

RheoLogic also maintains a permanent record of accepted, rejected, and remilled batches. In addition, an "Event Flag" marks batch records with such information such as "first lot of material from a new vendor, first batch after rebuilding the mixer," etc.

We at Seals Eastern are convinced the RheoLogic is an invaluable tool for applying statistical control to the production processes. However, additional steps are required to further refine batch mixing quality control. These include:

- Direct computer feedback control of the batch weigh-out process;
- Application of RheoLogic to the direct electronic collection and analysis of tensile and mooney test data. This will speed up physical testing and acceptance decisions.

These programs are currently in the development stage and should be installed by the end of 1985. At Seals Eastern, parallel efforts are underway to apply statistical process control techniques to other production areas, including performing, press operations and finishing. Process capability is being used to help establish specification limits. "P" charting is being used to control attribute data on the press line. "X bar-R" charting is being used to control variables in molding preforms preparations and to control machine finishing processes.

As was true in Materials Control Lab, we have found that manual applications of these statistical control techniques simply isn't possible. Here again, we are relying on a Paul Hertzler program, called QA/S, which accommodates direct data input from gages, and runs on the Hewlett Package "HP 150 Touchscreen" computer.

The QA/S system includes "X bar-R" control charting, short process capability, full capability analysis, and trend detectors such as run sum and scatter diagrams for variables. For attributes, "P", "NP", "U", and "C" control charts, and summary devices such as pie charts, pareto diagrams, and weekly, monthly or quarterly production quality summaries by operator, work center, inspector, etc. are available. We expect these tools to give us benefits comparable to those we have gotten in the Control Lab for RheoLogic.

"RheoLogic" is a registered trade name of the Paul Hertzler Co. "QA/S" is a registered trade name of the Paul Hertzler Co. "HP86B" and "HP 150 Touch screen" are registered trade names of the Hewlett-Packard Co.

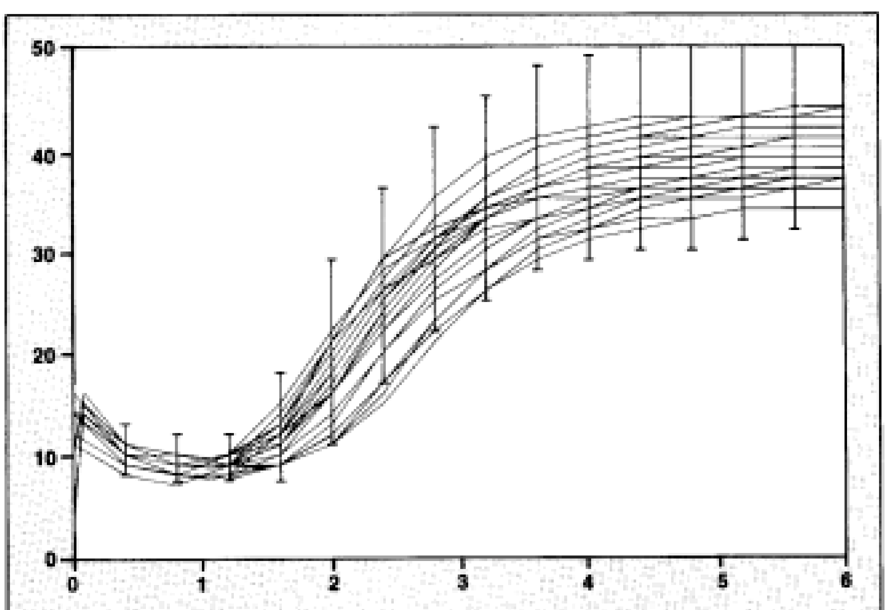

Fig. 4 — Rheology curves for 60 batches of compound 7013 selected over a five-month period.