THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

REPORT OF THE SRAMA

QUALITY FACT FINDING MISSION TO THE US

19TH MAY TO 3RD JUNE 1986

Report No 403

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ACKNOWLEDGEMENTS

SRAMA would like to thank the spring companies who made their staff available for the Quality Mission.

Grateful acknowledgement is also made to the Department of Trade and Industry for its initiative and financial support, and to the SMI and the participating American companies for their hospitality and co-operation.

1. INTRODUCTION

Sir Ewan Maddock, when he was Chief Scientific Advisor to the Department of Trade and Industry, said that when the Japanese require information they send a delegation round the world to identify that source of information and then go about obtaining and using it. The British, on the other hand, when faced with a similar problem, set up a university research project and, five years later, with a bit of good fortune, information is generated and a solution found to a problem that probably no longer exists.

The DTI, taking a leaf out of the Japanese book, and to their eternal credit, decided to sponsor a number of Fact Finding Missions for various industries and SRAMA was fortunate in obtaining support for one of the first to be commissioned. SRAMA's Council decided on the topic of "Quality" and that the study should take place in the USA.

The first decision was an easy one since improving quality is the major objective of all UK manufacturing industry: the choice of country was more difficult, the final decision being between Japan and the USA and, after careful consideration, the USA was selected for the following three reasons:

Firstly, the common language makes communication much easier in the US than in Japan; secondly, the customer "push" for improved quality is currently stemming from Detroit rather than Japan, and thirdly it was thought that good US practice would be easier to establish in the UK than Japanese practice, which is difficult to transplant to a very different cultural environment.

SRAMA Council appointed Mr E T Goss as Mission Leader and the following as members of the Mission:

Mr D A Blatherwick of Entex Springs Limited

Mr J F Moore of Salter Springs and Pressings Limited

Dr I Fisher of The Tempered Spring Company

Mr J A Bennett, Director of SRAMA

2. ITINERARY

The team, at its planning meeting, agreed that, in addition to spring manufacturers, wire drawers and makers of inspection and Statistical Process Control (SPC) equipment should also be visited, and that a meeting should be set up with Ford quality policy personnel. With reference to the selection of spring manufacturers, we asked the SMI (Spring Manufacturers' Institute) for guidance on the leading exponents of quality practice in the US. Their suggestions were followed up and their recommended firms visited, together with a number of other spring manufacturers, selected to provide a balance of size, location and markets served. In total, nine spring manufacturers, two wire mills and two manufacturers of inspection/SPC equipment were visited and discussions were held with the American Suppliers' Institute and a representative of Ford Motor Company.

All the companies whom we approached willingly agreed to a visit from the SRAMA delegation. The hospitality, the free exchange of information, and the help and assistance offered by our US hosts must be recorded and our sincere thanks are due to them.

3. STRUCTURE OF THE REPORT

Each member of the delegation prepared a short report on each company visited. In order to respect the confidentiality of our American hosts, this report has been prepared under subject, not company, headings, and and it is the intention to give an accurate picture of QA policy in the companies visited without disclosing practice in any particular company.

The report commences with a summary of the meeting with the American Suppliers' Institute and the Ford Motor Company. The next section deals with spring manufacturers, followed by a section on wire drawers and finally on SPC equipment. The conclusions attempt to draw together the most significant findings and discuss their potential for implementation in the UK.

4. POLICY DISCUSSIONS WITH THE AMERICAN SUPPLIERS' INSTITUTE

The original intention was to arrange a meeting with policy making personnel within the Ford Motor Company. During the process of establishing contact with the right individual, the American Suppliers' Institute was identified, and Mr Larry Sullivan, Chairman of the Board of Directors of the ASI, agreed to set up a meeting with a representative of the Ford Motor Company. This offer was taken up and proved very successful.

ASI is an independent successor to Ford Motor Company's Ford Supplier Institute, itself formed in 1981, and provides a series of courses and seminars on quality systems and related matters. It is guided by a steering committee of executives from major American companies and has strong links with equivalent organisations in Japan. Much of the training is based on the work of Dr Taguchi, an eminent Japanese statistician and Deming prize winner, who is an Executive Director of ASI. Dr Taguchi's expertise in the optimisation of design through the analysis of inter-related variables and solution of problems is a key area of ASI's operations.

Much of our time was spent talking to Lou Caira of Ford, who is responsible for world-wide SQA operations. He is more involved with policy than direct line control, and was involved at senior level in world-wide comparisons of the same vehicles built in different Ford plants and also the auditing of competitors' products.

Tracing the history of Ford's current deep commitment to quality, Lou Caira explained that a small group of managers from Ford had contact with with Dr Deming in late 1960 and managed to get top management involved from the start in an effort to match Japanese quality standards. At first, a fairly narrow view was taken, based on statistical process control alone, but it was soon realised that this was not sufficient and a broader view emerged.

Lou Caira stresses that the success of the whole programme has been based on the total commitment of the Board members and top management of Ford, including the President, who went back to the classroom to learn simple control charting techniques. With this level of commitment, it was impossible for lower managers to plead they had no time for training.

There was initially a joint effort between purchasing and quality assurance; purchasing putting pressure on QA to devise a quality system which could be applied to evaluate suppliers objectively and which has now developed into the Q1 designation of approved and preferred suppliers.

It was agreed, however, that a policy on paying for quality still had to be established. It was further acknowledged that the philosophy of operating a company with short-term goals is a hindrance to maintaining quality standards, with short-term profit goals occasionally allowing substandard quality to be condoned. It is significant that, in recognition of this, the remuneration package of Ford's top executives will in the future be geared to longer term goals rather than quarterly results.

Supplier evaluation at Ford is now based on 'Total Quality Excellence" which embraces product quality, service of supply, commercial considerations and technological back-up.

For the future, Ford's aim is to reduce the number of contacts between themselves and their suppliers from the point where engineers and quality personnel from four or five different divisions of Ford (and other large customers) have been maintaining contact with single suppliers.

In a similar vein, the Automotive Industry Action Group has been formed under the aegis of various supplier organisations to try and improve communications between suppliers and automobile manufacturers. Its aim is to encourage the use of industry-wide standards and it has so far succeeded in introducing a common bar-code. It is currently working on standards for quality systems with a view to reducing paperwork, but Lou Caira feels that the auto manufacturers will not accept a total audit of quality by a single arms-length body, although an independent audit of systems might be acceptable.

Lou Caira sees the drive in quality directed in the future towards continuous improvement, with every engineer every day making some improvement, however small. For this purpose the Taguchi method - simply a means of identifying and optimising critical parameters in any manufacturing process - will be pre-eminent. A mathematical technique based on the earlier work of R A Fisher, the power of the Taguchi method is in reducing the number of experiments which have to be carried out in order to produce the desired information. It can be seen, therefore, that the Taguchi method follows on logically from quality systems and SPC, since it is concerned with process optimisation and the identification of those parameters which need the strictest control, and its application, in the long term permits a much more logical approach to quality problem solving.

To this end, 4000 Ford engineers world-wide will be trained in Taguchi methods, and teams comprising one individual from each of purchasing, SQA, and product engineering will present case studies from suppliers and from Ford plants.

Insofar as we usually see Ford of Britain pursuing similar quality policies and systems about 18 months behind Ford of America it was interesting to have a preview of what is in store for us.

5. SPRING COMPANIES

i) Statistical Information on the Spring Manufacturers Visited

The Mission visited nine spring manufacturing companies, representing a total turnover of $330 million, or approximately one third of the US spring industry output, and ranging in size from 50 to nearly 3000 employees. Only four of the companies visited had just one US manufacturing plant, and the nine companies had a total of 38 manufacturing plants within the US. The total employment covered by the nine companies was approximately 4500 people, and the sales per employee ranged from $70,000 to $100,000. Of all the companies visited only the largest was a public company, all the others being family-owned and controlled concerns. The geographical spread of the companies was from Connecticut in the East to California in the West, and they were founded over a period in excess of 100 years, four in the last century, one just prior to the Second World War and the remainder later than 1955.

ii) Comparison of US and UK Spring Companies

Two facts emerge from the information listed above. Firstly, the American spring industry is still largely family-owned and run, the trend in the UK over the past ten years, of public companies purchasing family owned spring businesses, not having taken place in the US. The second startling fact is that the sales per person employed figure is three times higher in the US than in the UK, which approximately reflects wage rates, but takes no account of material prices which are compatible between the two countries. Thirdly, batch sizes in the US are generally larger than in Europe and companies tend to produce fewer part numbers. Fourthly, there was a greater investment apparent in computer and CNC technology in the US with a range of CNC coilers in evidence, particularly noticeable in the tool room area where most companies had CNC machines and some degree of CAD/CAM support. Finally, wire supplied in the US is almost exclusively from local stockists, with very little being purchased directly from the manufacturers. Material supply lead times are consequently very short, typically 24 hours, and hence wire stocks, even in large companies, are very small.

Other observations in comparing the spring industry in the two countries is that the general standard of housekeeping and presentation is superior in the US to the UK. Many US spring factories are located on factory estates which are well landscaped.

American factories are still mainly equipped with American made machinery, with Torin dominating the coiler population. (While we were in the States, concern was expressed about the future of the Torin Corporation, but now we understand it has been rescued from bankruptcy by a Connecticut organisation.) The majority of four-slides are Nilson, while Gardner and Bessley dominate the grinding machinery. European springmaking machinery has only a very small penetration in the US market. Japanese (Itaya and MEC machines were seen but not in great numbers, as were some very cheap coiling machines from Taiwan and mainland China.

As in the UK, some plants were unionised while others were not and the general impression gained was that the unions, as in the UK, are much less powerful than they were in the late 70s.

iii) Attitude Towards Quality

There is no doubt that the American spring industry has taken quality to heart. By way of example, in one senior executive's office the motto on the wall read "Quality is our way of life". The brochure of another spring company underlines its quality performance and says, "in short ..... offers you quality you can depend on". As we approached a third company, the first thing we saw was the Ford Q1 flag flying from the masthead. The brochure of a fourth company proudly announces on the cover "manufacturers of quality springs". Not only was quality embossed upon company stationery, it also preoccupied the conversation of senior executives.

The answer to the question, "When and why this interest in quality", is very simple; it was a result of customer demand and occurred in 1981. The customer pressure came from the motor industry and, in particular, from Ford. Although the pressure for improving quality was external to the spring industry, all the companies we visited are now fully convinced that in order to stay in business, let alone prosper, it is essential to become a quality company, that is supplying the correct components on time at an acceptable price.

The impact of product liability legislation in the US has created a financial incentive for improved quality and is in a way another form of customer pressure, this time applied through US legislation rather than purchasing power.

Having been convinced that quality is important, the leadership must come from the top. Top management has not only to be convinced that quality is important, it has to be evangelical about the matter and, in particular, learn the skills associated with quality. The Mission was told on many occasions that it is quite pointless sending the chief inspector or shop floor personnel on quality or SPC courses and expecting a significant change in the company to occur. Training for quality, which will be dealt with in the next section, must start with training at the top, and the executive vice-presidents of all the leading companies we visited were quite familiar with SPC practice and able to complete SPC charts themselves. Leading by example is essential.

iv) Training for Quality

Of the nine spring manufacturers visited, one company intends to keep away from quality demanding customers for as long as possible, and has therefore not embarked upon a training programme. Two further companies had not undertaken formal quality training but professed a good quality record with their customers. Of the remaining six companies, three had implemented an across-the-board comprehensive quality training schedule; one had used training techniques to change attitudes but only to a limited extent to teach skills; while the two remaining companies, who have installed (and in one case developed) fully automatic SPC plotting equipment, had mounted training courses to meet their somewhat different needs. As one put it "we do not have to train shop floor personnel how to use SPC but how to respond to the information it provides". As another senior executive pointed out, after SPC training the operative doesn't inform his supervisor, "I think it is going wrong", but now says "I know it is going wrong".

Quality training has two distinct but related aspects. The first is to instil into the workforce (management included) that quality is important and is essential for survival. As one company put this message over to its workforce, "If we lose an order due to poor quality you could lose your job - no orders, no jobs". The second function of quality training is to teach the skills necessary to operate quality systems, and this in particular means SPC charting.

With regard to the companies who had implemented a comprehensive across-the-board training scheme, a number of common points emerged. Firstly, the training is a mixture of indoctrination and teaching skills. As far as the indoctrination is concerned, use was made of video presentations and, for example, the sixteen videos produced by Dr Juran headed "Juran on Quality Improvement". The second aspect of teaching SPC skills was normally taught from in-house material, although management and selected personnel have been sent on Ford and other customer quality courses and also to the SMI/SPC course, which has been successfully run on seven occasions in the States.

The length of training is between thirty and forty hours for top, middle and first-line management, and sixteen hours for shop floor personnel. The time allocation in the forty hour training course is divided equally between quality improvement and SQC training. The latter starts with concepts of SQC and Pareto diagrams leading through histograms, graphs and scatter diagrams, process capability studies, control charts, sampling, on up to case studies and, in some cases, Taguchi methods. The forty hour training programme is presented in fifteen or sixteen sessions on a once or twice a week basis. The shop floor training of sixteen hours, which is divided into five sessions, has a breakdown as follows; SQC concepts, variation, measurement and two sessions devoted to charting.

Training in the States is quite often undertaken outside working hours with, as far as we could see, no compensation to the workforce, the argument being that training enhances the market value of the employee. One company did its training on Saturday mornings, while others used evening classes in conjunction with the local technical colleges. The message came through that, where comprehensive training is to be undertaken, it must first be planned, it must start at the top and it should be taught and implemented on a departmental basis.

v) Shop Floor Quality Practice - Use of SPC

With the exception of one company, the Mission was shown the manufacturing facilities and shop floor practice, and so this section of the report deals with what was actually taking place on the shop floor at the time of the visit. An attempt has been made to make this section of the report informative, while at the same time not disclosing practices operated in any particular company.

Of the nine companies visited, four are making extensive use of SPC techniques. Needless to say, the motor industry is the principal market for these companies and all four companies became involved in SPC in the period 1980-1982.

As mentioned earlier under Training for Quality, we saw two approaches to the implementation of SPC, the first involving the training of operatives to complete control charts. The second, pioneered by one Chicago company, used direct data recording from on-line measuring equipment, the data being displayed by the machine and, in some cases, linked to a central computer by internal telephone lines. It is interesting that two companies who are not currently making extensive use of SPC but intend to use SPC on specified jobs in the near future are experimenting with on-line data logging. The claim made by the principal user of on-line recording techniques is that "the machines do the work not the operator, the operator does not have to worry about plotting the figures correctly and management doesn't have to worry that the results have been fiddled." One further company is currently using SPC on 10% of its jobs, while the remaining two companies do not serve markets which currently demand SPC procedures, but are well aware in one case that customer demands may be made in the future and have already made plans for training operatives.

The four companies who are making extensive use of SPC techniques are all, to a greater or lesser extent, using them for process improvement, and, where the data logging system is installed, the equipment has been used to compare raw materials from different sources and also to examine in detail the effect of such parameters as production speed on tolerances achieved.

Only one company, as far as we could determine, is currently using, or says it is using, Taguchi techniques for problem solving and process improvement.

In all companies making extensive use of SPC, the manually charted data were entered by the operators. However, one company making occasional use of SPC uses its existing inspection personnel to take the readings and plot the charts. Companies not using SPC use "go/no-go gauges", as in the UK and, presumably, elsewhere.

In the mechanics of SPC charting, a sample size of five appeared to be the norm and the frequency of sampling on a time basis ranged between four times and once per hour. Median and range charts were preferred to average and range charts on the basis that they were easier for the operator to work with, albeit not so informative.

First off and final inspection is still carried out in most plants. The inspection equipment seen was not particular sophisticated but, in many cases, consisted of fairly old load testers which had been fitted with load cells and linear transducers feeding the output into a dedicated computer so that statistical data were computed and plotted.

Quality circles were not used in any of the companies we visited. One company was of the impression that, in the implementation of a quality package, quality circles can only be introduced after much else has been achieved. Other companies, we presume, had considered and dismissed quality circles. It may be that they do not fit the American cultural background and perhaps are something special to Japan.

To summarise quality practice it, like all quality initiatives, is customer-led, and those spring companies supplying customers who demand specified quality procedures have to implement them. One company is successfully pioneering the application of automatic SPC charting and it will be interesting to see how many others follow this approach. In general, those companies which have applied SPC appreciate that it gives them information, not opinions, from the shop floor. Companies are also extending SPC techniques to optimise process and material parameters.

The cost effectiveness of SPC techniques was discussed with the companies using them. One company is totally convinced, through keeping accurate records, that SPC is cost effective and that the cost of returns is now only 1% of what it was in 1980. Other companies were not so convinced, but believe that, in the long term, it will be, and that if they wish to continue to supply customers who demand SPC they will have to use it anyway. There were some indications that customers are prepared to pay a slightly higher price for guaranteed quality, but this is by no means universal.

vi) Vendor Ratings and Third Party Accreditation

None of the spring manufacturers we visited is currently carrying out vendor ratings, although one company supplying the automotive industry was visiting their wire suppliers and offering assistance to set them up with SPC, initially by providing their own training material. Those associated with the motor industry seem to have a good knowledge of their material suppliers' capabilities and, in most cases, relied on their release certificates, although in some cases random checks were also carried out.

Third party accreditation, as defined by BS 5750, is not being operated in the US. Such practices are, we presume, alien to the American way of doing business, and may also be illegal under the same acts which prevent meaningful co-operative research being undertaken.

6. WIRE MANUFACTURERS

Two substantial wire mills were visited, the American Spring Wire Corporation in Bedford Heights, Ohio, and National Standard Wire in Niles, Michigan. The companies have very different historical backgrounds: National Standard was founded in 1907 and American Spring Wire as recently as 1968.

Both companies pride themselves on being producers of quality wire and both have invested substantially in improving their product quality. Both have long term plans for improving their quality image and performance still further.

Although in many ways the companies are very different, a number of common features were evident. Both companies realise that the quality of wire they produce is a function of the quality of the rod they use. Hence both companies monitor and audit the quality of rod received from their suppliers, and both expressed long term concern regarding the viability of rod mills on a worldwide basis. They have both sensed a reluctance in rod rollers to invest in new plant and expressed the fear that quality rod will be difficult to obtain when current plants become obsolete.

As far as relationships with customers were concerned, neither company received formal quality audits from the spring industry, although they both worked closely with their customers on quality matters, a point of view which was supported by visits to spring manufacturers.

Both companies have been operating SPC for the past two to three years and have embarked on an extensive training programme. SPC is difficult to apply to a continuous process such as wire drawing, but was used to chart tensile strengths and wire diameter, normally measured at coil ends. Both companies believe that the way ahead is to obtain a better understanding of the wire drawing process and to control and chart those process variables which affect wire quality. Companies are in a position to supply SPC data to spring companies on demand.

The wire manufacturers claim that, in contrast to spring manufacturers, the initiative for improving quality was internal not customer demand. One of the wire mills had set up a pattern of weekly meetings aimed at improving quality, which was the nearest thing we saw to quality circles in the States.

The most noticeable difference between the two wire mills visited was that one had adopted a policy of attaining quality through continuous process development, whereas the other company aimed at the quality image by providing a problem solving service. Consequently, the pattern of investment in the two companies was noticeably different.

7. SPRING TESTERS AND SPC EQUIPMENT MANUFACTURERS

The Link Engineering Company has been manufacturing spring load testers in Detroit for fifty years. They advertise regularly in the Springs Magazines and their products are used extensively by the American spring industry, but the Company is virtually unknown in Europe and the UK.

I believe that for many years the Company did not introduce new models of spring testers, but recently progress has been made and one of their latest developments is a high accuracy load tester which is capable of 0.01% accuracy on load.

The second manufacturer of SPC equipment for the spring industry was the TPC Technology Group of Elk Grove Village, Chicago, Illinois, which is a subsidiary of North American Spring & Stamping Corporation. The claim of the TPC monitors is that they operate on the production floor, generating real time SPC information automatically from machine sensors. The Mission was impressed with this product and approach to SPC logging.

8. GENERAL CONCLUSIONS

1. Improving quality performance is a major preoccupation with the American spring industry.

2. The impetus to improve quality has come from the spring industry's customers, principally the motor industry led by the Ford Motor Company.

3. In order for a company to improve its quality performance, the initiative, drive and commitment must come, and be seen to come, from the chief executive.

4. Comprehensive and extensive training is necessary before quality improvement can be obtained. The training consists of two elements, indoctrination in the importance of quality, and teaching quality techniques.

5. More opposition was experienced from middle management than from shop floor personnel in the application of new quality procedures and methods.

6. Taguchi methods will increasingly be used to improve quality through process optimisation and control.

7. The implementation of SPC was an essential element of improving quality in the companies which were visited.

8. Opinions differed on whether the introduction of SPC and allied quality techniques were self-financing, but spring manufacturers did agree that the introduction of these techniques was essential for long term survival.

9. Quality circles have not been successfully introduced into the American culture.

10. The impetus in improving quality performance in wire mills was claimed to be internal rather than external.

11. Although limited SPC charting can be applied to wire manufacture, long term improvements will only be made through a better understanding of those wire drawing parameters which affect wire quality.

12. The American spring industry makes extensive use of spring load testers, employing load cells and linear transducers, coupled to a micro computer for the display of the statistical information. Similar techniques are used on presswork, where the input comes from digital micrometers.

13. The growth of automatic on-line SPC charting procedures should be monitored with interest.

THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

APPENDIX

to Report No. 403

Statistical Techniques for the Spring Industry

The appendix is a record of the management and statistical techniques employed by Spring Manufacturers in the United States to control the quality of their products. Of the techniques listed the most widely used are capability studies and control charting for variables.

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TYPES OF DATA

VARIABLES — IS DATA WHICH REPRESENTS MEASUREMENTS TAKEN ON A CONTINUOUS SCALE (FOR EXAMPLE, MICROMETER TYPE MEASUREMENTS).

ATTRIBUTES — IS DATA WHICH REPRESENTS ONLY THE NUMBER OF ITEMS CONFORMING AND THE NUMBER OF ITEMS NONCONFORMING (FOR EXAMPLE, GO/NO-GO GAGE TYPE MEASUREMENTS).

POSSIBLE APPLICATIONS:

VARIABLES (THOSE CHARACTERISTICS THAT ARE MEASUREABLE.)

- FREE LENGTH
- LOAD
- O.D.
- SOLID HEIGHT
- DEFLECTION
- WIRE DIAMETER
- WIRE TENSILE

ETC.

ATTRIBUTES (THOSE CHARACTERISTICS THAT ARE CLASSIFIED AS "GOOD" OR "BAD".)

- SURFACE COLOR
- NUMBER OF SPRINGS REJECTED VS. SPRINGS TESTED
- ACCEPTABLE GROUND ENDS
- SPRINGS DYE APPLIED
- DAMAGE
- SPRINGS SORTED AT COILING FOR FREE LENGTH
- GOOD WIRE CAST VS. BAD

ETC.

GENERAL DATA COLLECTION OUTLINE

DECIDE WHY WANT TO OBTAIN DATA

- FIND VARIATION
- IMPROVE PROCESS
- DETERMINE IF IN CONTROL
- TO DETERMINE CAPABILITY
- TO ALERT OPERATOR WHEN TO MAKE ADJUSTMENTS

CHOOSE CHARACTERISTIC(S) TO OBTAIN DATA

- DRAWING OR SPECIFICATION REVIEW
- HOW DETERMINED (BY WHOM, WHEN)

CHOOSE MACHINE OR PROCESS THAT AFFECTS SELECTED CHARACTERISTIC(S)

DECIDE WHAT TECHNIQUES OF DATA COLLECTION AND ANALYSIS SHOULD BE USED

- USE PROPER STATISTICAL TECHNIQUES TO ANALYZE DATA
- SAMPLE SIZE
- FREQUENCY

DEFINE PROCESS CONDITIONS

- OPERATING
- CHEMISTRY
- MATERIAL

MAKE SURE THAT PROCESS OR MACHINE IS OPERATING TYPICALLY

- WANT TO SEE TYPICAL VARIATION OVER TIME
- SELECT REPRESENTATIVE OPERATOR
  - OPERATOR MUST UNDERSTAND PURPOSE
  - OPERATOR MUST TRUST EFFORT
  - OPERATOR MUST NOT BE BEST OR WORST

PROVIDE ADEQUATE AND NORMAL MATERIAL FOR PROCESSING

- SHOULD NOT BE BEST OR WORST
- SHOULD BE PROPERLY IDENTIFIED TO ASSURE TRACEABILITY

PROVIDE ADEQUATE GAUGING AND DEFINE METHOD FOR MEASURING

- ACCURATE
- CALIBRATED
- OPERATORS PROPERLY TRAINED

METHOD TO KEEP TRACK OF THE ORDER IN WHICH DATA IS COLLECTED

- MAKE ANY NOTES OR ANY VARIATIONS SO EFFECT CAN BE EVALUATED
- MAINTAIN IDENTIFICATION FOR PROCESS MATERIAL

OBSERVE MACHINE OR PROCESS TO ASSURE OPERATED TYPICALLY

- COLLECT DATA AS PLANNED
- NOTE ANY SIGNIFICANT OBSERVATIONS

USE COLLECTED DATA FOR ANALYSIS AND EVALUATION

- PERFORM ANALYSIS AS PLANNED
- EVALUATE DATA FOR APPROPRIATE ACTION

SPC TECHNIQUES APPLICABLE TO SPRING MAKING:

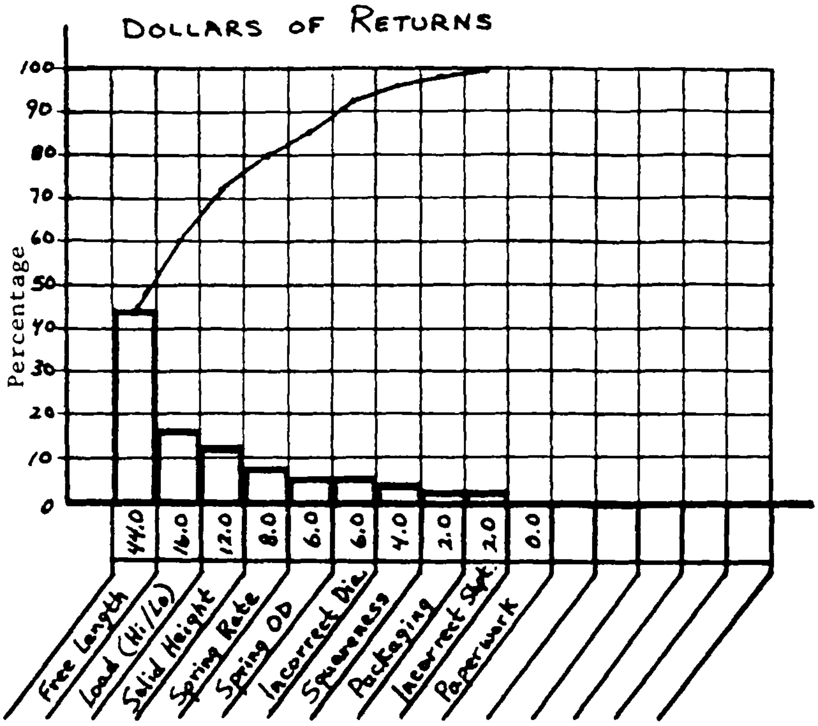
- PARETO
- FLOW CHARTING
- HISTOGRAM
- SCATTER GRAPHS
- CAUSE & EFFECT ANALYSIS
- VARIABLES CONTROL CHARTING
  - RUN CHARTS (X)
  - X CHART WITH MOVING RANGE (R)
  - MEDIAN
  - MEDIAN & RANGE
  - $\overline{X}$, R
  - $\overline{X}$, s
  - PRE-CONTROL
- ATTRIBUTES CONTROL CHARTING
  - p
  - np
  - c
  - u
- CAPABILITY STUDIES
  - MACHINE
  - PROCESS

PARETO - METHOD TO VISUALLY RANK PROBLEMS OR CAUSES OF VARIATION IN DESCENDING ORDER.

SUMMARY GUIDELINE (NOT A PROCEDURE):

- CHOOSE ITEMS (DEFECTS, DOLLARS, PROBLEMS, ETC.) THAT HAVE MEASUREABLE FREQUENCIES OF OCCURRENCE.
- CHOOSE PARAMETERS OF DATA COLLECTION (FOR EXAMPLE, ALL DEFECT CATEGORIES DURING A GIVEN YEAR).
- COLLECT DATA ACCORDING TO CHOSEN CATEGORIES.
- ACCUMULATE TOTAL OCCURRENCES AND/OR AMOUNTS FOR EACH CATEGORY AND CALCULATE PERCENTAGES OF TOTAL REPORTED.
- DRAW VERTICAL AND HORIZONTAL AXES (GENERALLY, OCCURRENCES OR PERCENTAGES ARE ON THE VERTICAL AXIS).
- INDICATE ON THE HORIZONTAL AXIS THE CHOSEN CATEGORIES IN DESCENDING ORDER BEGINNING AT LEFT AXIS.
- EXTEND BARS FOR EACH CATEGORY TO APPROPRIATE VALUE ON VERTICAL AXIS.
- IF DESIRED, DETERMINE ACCUMULATED FREQUENCY FOR DESCENDING VALUES OF CATEGORIES, PLOT POINTS, AND CONNECT LINES.

PARETO CHART



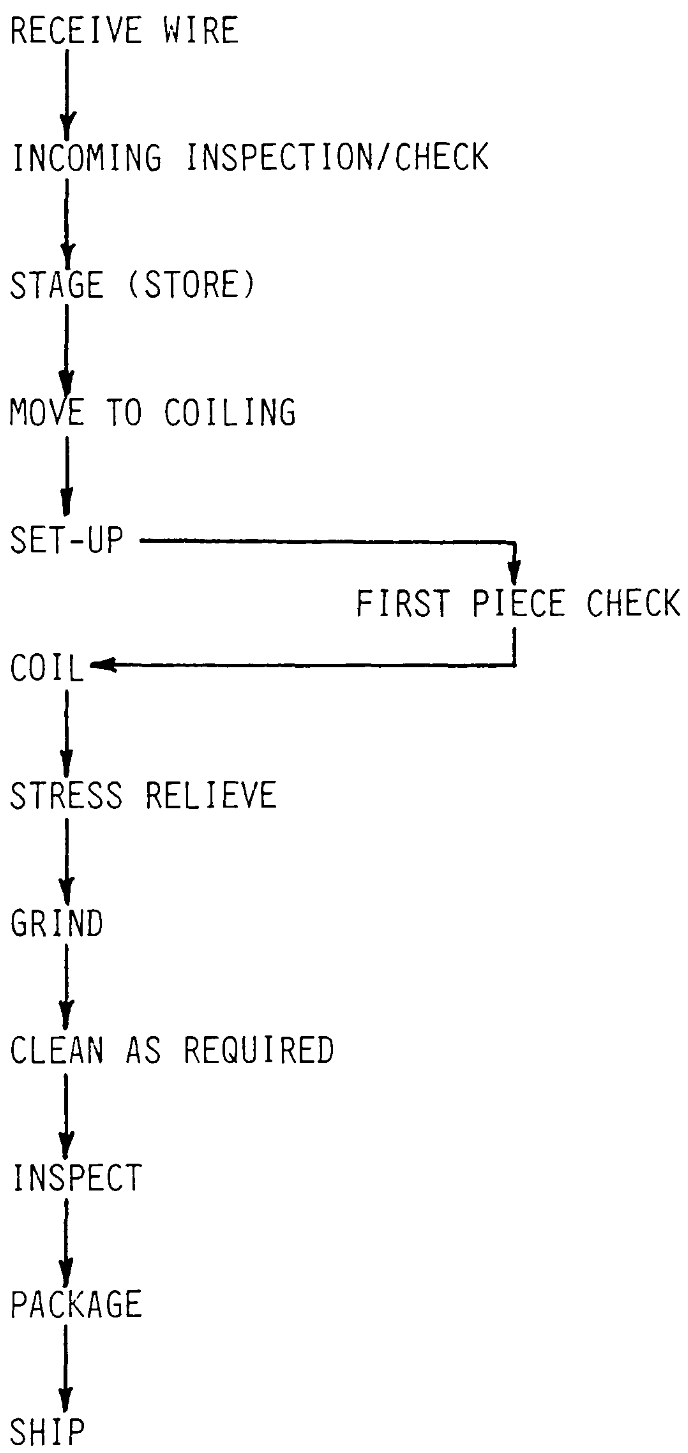
Categories	Occurrences	% of total occurrences	Rank		Value $	% of total value	Rank
Solid Height	4	10.0	3		600	12.0	3
Packaging	2	5.0	7		100	2.0	8
Spring Rate	2	5.0	8		400	8.0	4
Load (Hi/Lo)	8	20.0	2		800	16.0	2
Paperwork (certs, reports)	3	7.5	5		0	0.0	10
Spring OD	4	10.0	4		300	6.0	5
Incorrect Shipment	1	2.5	9		100	2.0	9
Free Length	12	30.0	1		2200	44.0	1
Incorrect Dimensions	1	2.5	10		300	6.0	6
Squareness	3	7.5	6		200	4.0	7
	40	100.0			$ 5000	100.0	

FLOW CHART - DIAGRAM TO VISUALLY PRESENT IN SEQUENCE THE STEPS OF A PROCESS.

SUMMARY GUIDELINE (NOT A PROCEDURE):

- SELECT PROCESS TO BE STUDIED.
- ISOLATE EACH STEP FOR MANUFACTURE OF PRODUCT OR PART NUMBER.
- MAKE SURE THAT STEPS INCLUDE STORAGE, STAGING, TESTING, PACKING, SHIPPING, ETC.
- LIST STEPS IN SEQUENCE OF PROCESSING (GENERALLY VERTICALLY WITH FIRST STEP AT TOP).
- BRIEFLY DESCRIBE EACH STEP FOR IDENTIFICATION.
- DRAW ARROWS TO INDICATE PROCESS FLOW.

FLOW CHART EXAMPLE



AEC - 5490 Compression

Free Length .750 ±.010

[signature] 4/12

1	.7508	.7524	.7536	.7532	.7526			
2	.7490	.7494	.7488	.7506	.7452			
3	.7536	.7516	.7540	.7528	.7504			
4	.7448	.7468	.7434	.7464	.7464			
5	.7504	.7502	.7516	.7532	.7512			
6	.7518	.7480	.7492	.7494	.7546			
7	.7512	.7490	.7482	.7502	.7484			
8	.7502	.7506	.7500	.7502	.7492			
9	.7526	.7536	.7536	.7454	.7502			
10	.7436	.7504	.7476	.7480	.7486			
11	.7488	.7472	.7480	.7474	.7464			
12	.7500	.7492	.7524	.7514	.7514			
13	.7474	.7468	.7514	.7490	.7474			
14	.7504	.7516	.7500	.7592	.7536			
15	.7490	.7538	.7474	.7512	.7520			
16	.7530	.7518	.7508	.7598	.7486			
17	.7492	.7510	.7510	.7490	.7470			
18	.7484	.7476	.7484	.7528	.7488			
19	.7510	.7490	.7502	.7502	.7514			
20	.7502	.7500	.7490	.7500	.7486			

TALLY SHEET - METHOD OR AID TO COLLECT DATA AS RANDOM MEASUREMENTS OR AS GENERATED OVER TIME TO VISUALLY PRESENT A DISTRIBUTION PATTERN AND RANGE.

SUMMARY GUILDELINE (NOT A PROCEDURE):

- DETERMINE CHARACTERISTIC TO BE EVALUATED.
- INDICATE PERTINENT INFORMATION ON SHEET.
- COLLECT DATA, INDICATE INDIVIDUAL VALUES (DIMENSIONS, MEASUREMENTS) OR CELLS IN LEFT VALUE COLUMN.
- RECORD THE INDIVIDUAL VALUES BY RECORDING DISTRINGUISHING MARKS (FOR EXAMPLE, X'S) IN THE TALLY SECTION.
- WHEN COLLECTION IS COMPLETED, ADD MARKS IN EACH ROW AND ENTER IN TOTAL/FREQUENCY COLUMN.
- ADD NUMBER OF VALUES AND CALCULATE TOTAL FOR ALL OBSERVATIONS.
- REVIEW FOR DISTRIBUTION PATTERN AND RANGE.

TALLY SHEET

AEC- 5490 Compression
Free Length .750 ± .010

Dimension Cell Interval	Tally	Total
UP .7600		0
.7599 .7580	XX	2
.7579 .7560		0
.7559 .7540	XX	2
.7539 .7520	XXXXX XXXXX XXXXX X	16
.7519 .7500	XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX XXXXX X	36
.7499 .7480	XXXXX XXXXX XXXXX XXXXX XXXXX X	26
.7479 .7460	XXXXX XXXXX XXX	13
.7459 .7440	XXX	3
.7439 .7420	XX	2
.7419 .7400		0
		100

HISTOGRAM - BAR GRAPH OF FREQUENCIES OF OCCURRENCES OR CLASSES OF MEASUREMENTS OR OBSERVATIONS (DATA). IT PROVIDES A PICTURE OF A PROCESS DISTRIBUTION BASED UPON THE COLLECTED DATA.

SUMMARY GUIDELINE (NOT A PROCEDURE):

- SELECT VARIABLE TO STUDY AND DECIDE IF WILL USE HORIZONAL OR VERTICAL FORMAT.

- COLLECT DATA (TRY TO COLLECT AT LEAST 30 OBSERVATIONS) AND CALCULATE RANGE (HIGHEST VALUE MINUS LOWEST VALUE).

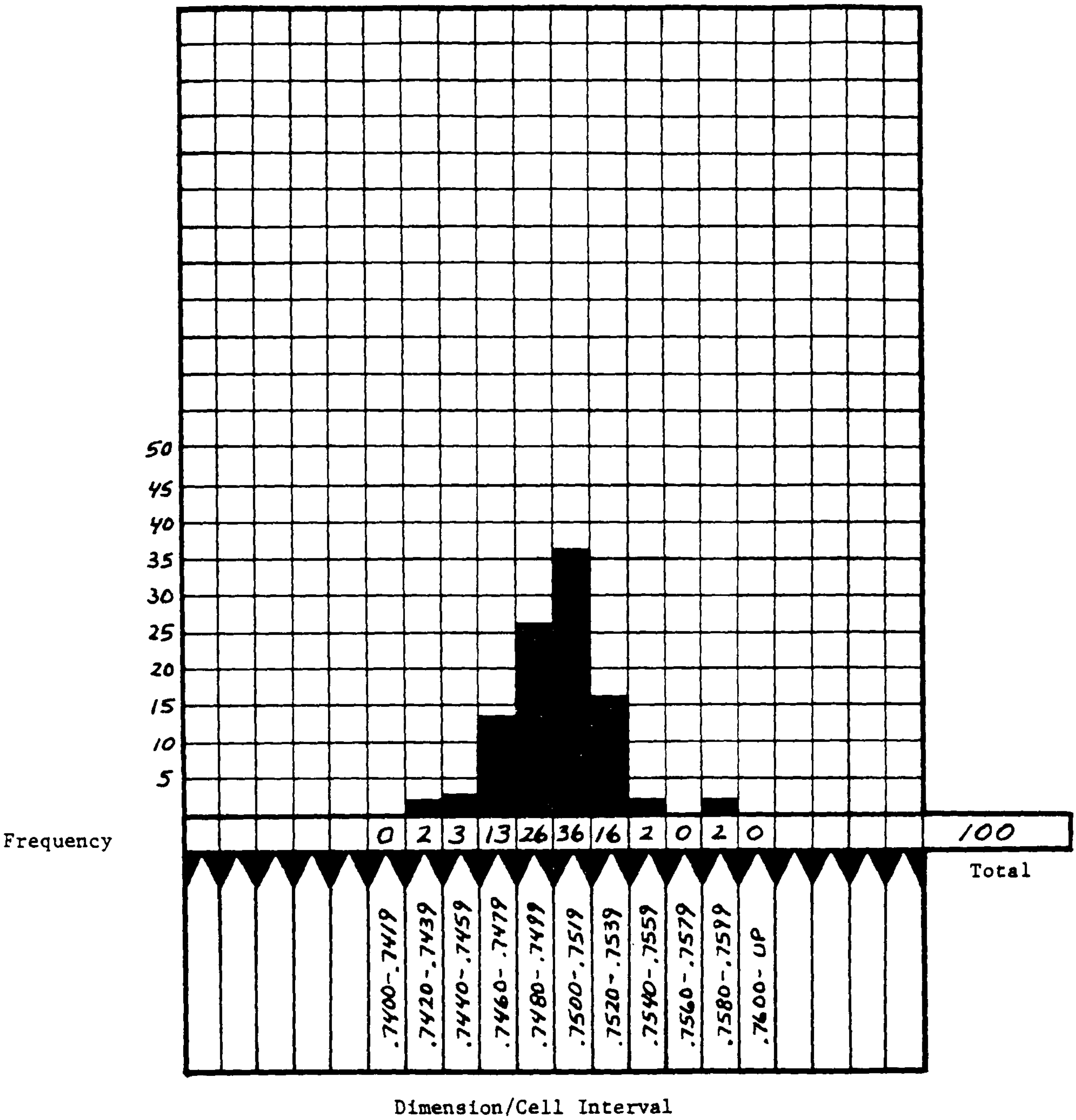
- DETERMINE NUMBER OF CLASSES (BARS). THERE ARE METHODS TO CALCULATE THE NUMBER, BUT 7 TO 15 IS A GOOD GUIDELINE.

- TRY TO ESTABLISH BOUNDARIES OF THE CLASSES SO THAT THE ACTUAL COLLECTED VALUES DO NOT FALL ON THE BOUNDARY LINES. IT IS RECOMMENDED THAT EACH BOUNDARY UNIT SHOULD BE HALFWAY BETWEEN EACH MEASUREMENT UNIT.

- PLOT FREQUENCIES OF MEASUREMENTS OR OBSERVATIONS IN THE APPROPRIATE CLASS BOUNDARIES.

- REVIEW OVERALL PLOTS TO OBTAIN A VISUAL CONCEPTION OF THE DISTRIBUTION OF COLLECTED DATA.

HISTOGRAM



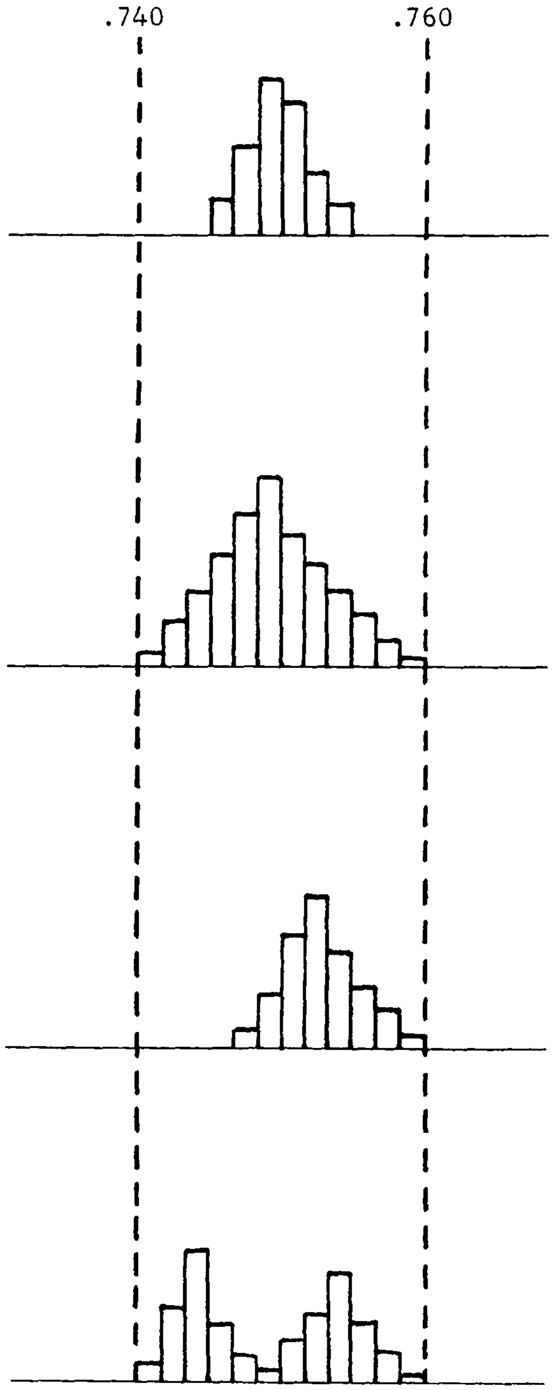
AEC-5490 Compression

Free Length .750 ± .010

TYPICAL HISTOGRAM INTERPRETATIONS

REVIEW PROCESS AND HISTOGRAM TO DETERMINE IF PROCESS CAN MEET SPECIFICATION LIMITS.

MUST LOOK AT THE CENTER, RANGE, AND SHAPE OF THE HISTORGRAM.



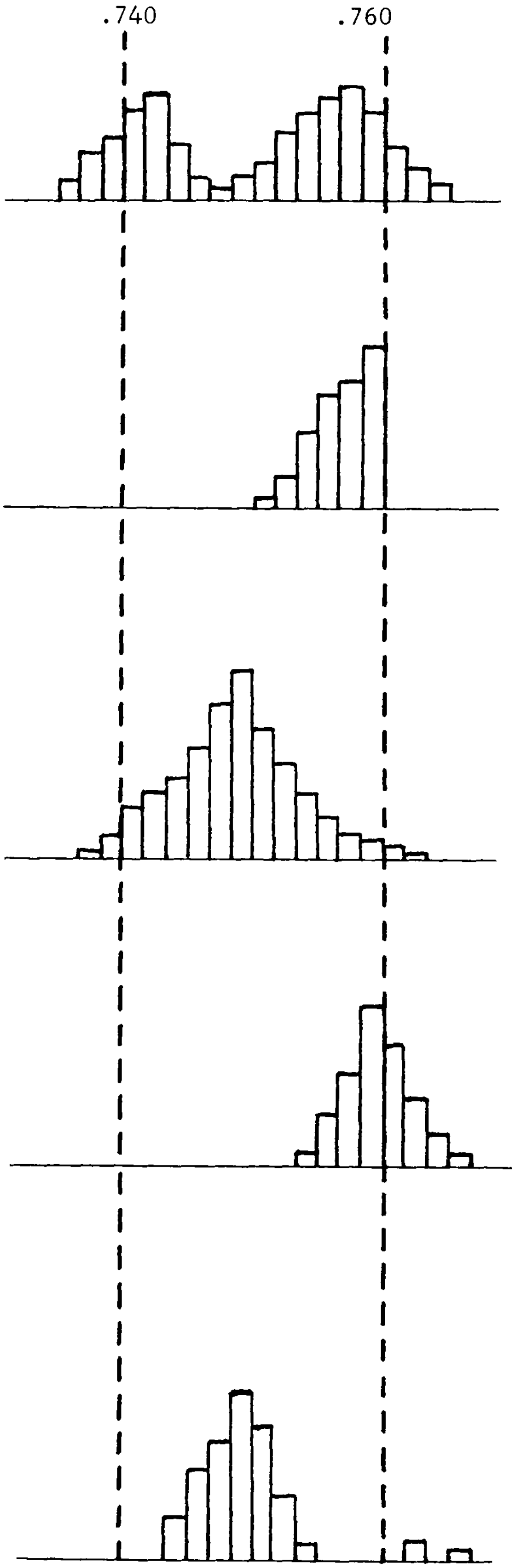
1. PROCESS CENTERED AND GOOD SPREAD. THERE IS ABOUT 75 TO 80% OF SPECIFICATION LIMITS.

2. PROCESS IS CENTERED AND RANGE IS TOTAL SPECIFICATION. ANY PROCESS SHIFT WILL RESULT IN SOME NONCONFORMANCE.

3. DATA IS WITHIN SPECIFICATION BUT MAY BE A PROBLEM IF SHIFT ANY MORE TO RIGHT.

4. BI-MODAL EFFECT. COULD BE EITHER TWO PROCESSES, TWO MACHINES, OR PROCESS HAS PROBLEM. HOWEVER, DATA IS WITHIN SPECIFICATION.

TYPICAL HISTOGRAM INTERPRETATIONS (CONT.)



5. BI-MODAL EFFECT WITH PROCESS NOT CAPABLE. COULD BE TWO MACHINES, MATERIALS, AND SO ON.

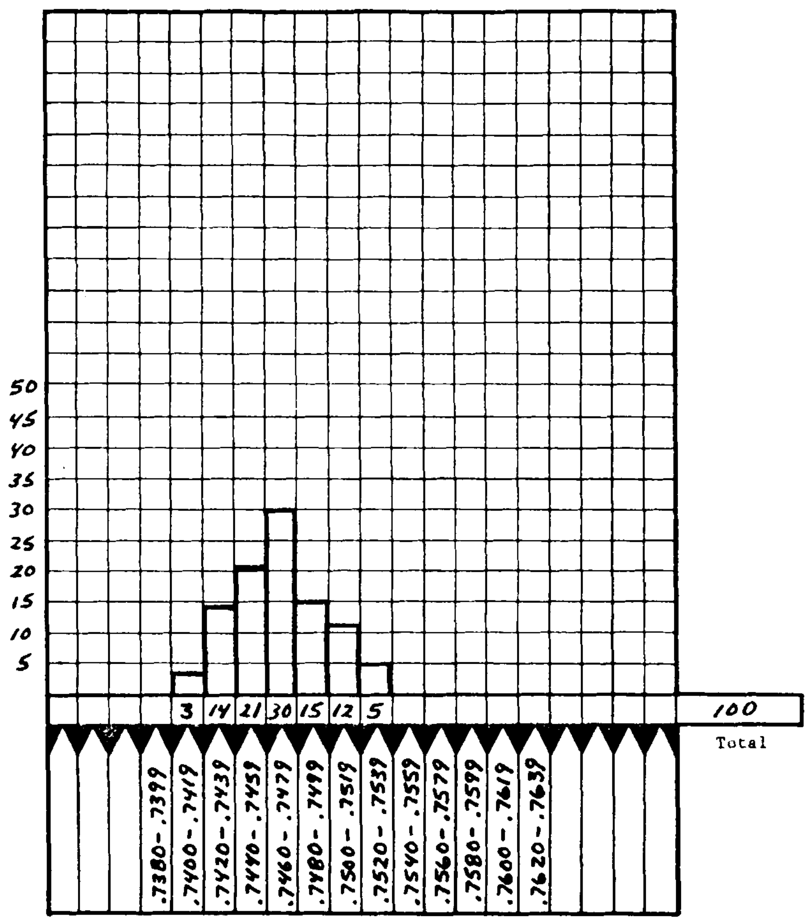
6. THIS INDICATES DATA WAS SORTED PRIOR TO EVALUATION.

7. PROCESS CENTERED BUT NOT CAPABLE. WILL ALWAYS HAVE NONCONFORMANCE WITH THIS PROCESS.

8. PROCESS RANGE IS CAPABLE, BUT MUST SHIFT PROCESS TO LEFT.

9. PROCESS CAPABLE, EXCEPT FOR A FEW DATA POINTS. PERHAPS CAUSED BY MEASURING ERROR OR AN UNUSUAL VARIABLE IN PROCESS. COULD INDICATE START-UP PROBLEM.

HISTOGRAM

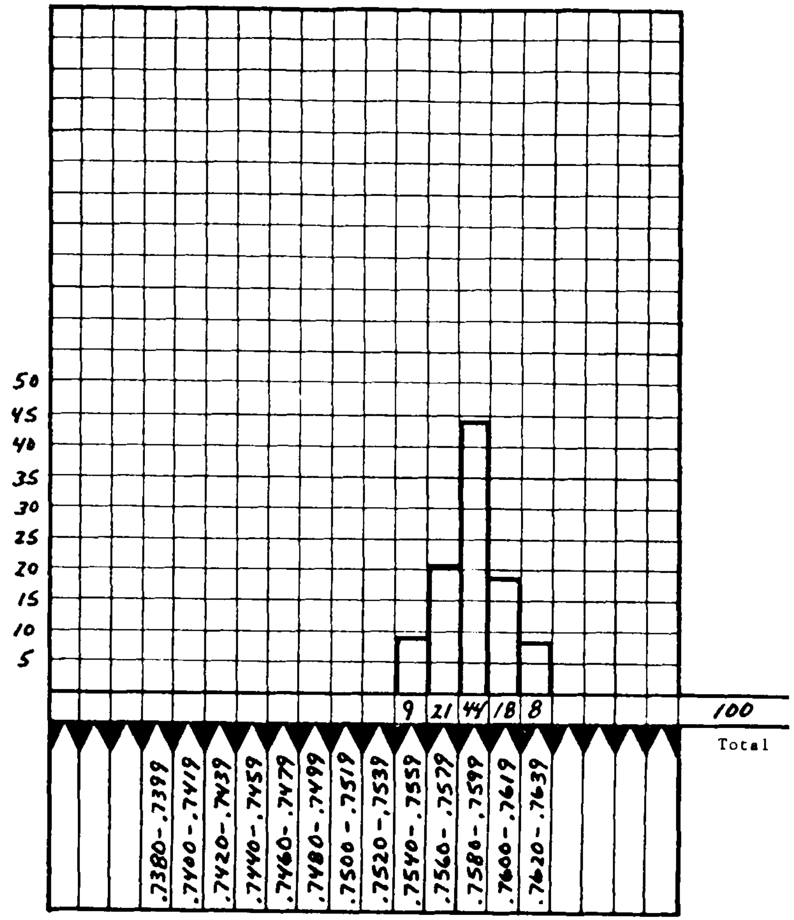


Dimension/Cell Interval

AEC-5490 Compression Lot #1

Free Length .750 ±.010

HISTOGRAM



Dimension/Cell Interval

AEC-5490 Compression Lot #2

Free Length .750 ±.010

SCATTER GRAPH - VISUAL DISPLAY OF THE CORRELATION OF TWO VARIABLES.

SUMMARY GUIDELINE (NOT A PROCEDURE):

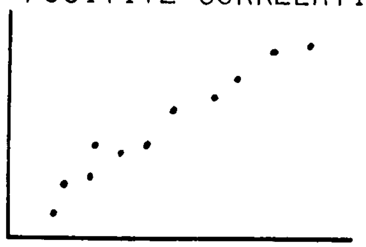
- OBTAIN SAMPLES OF DATA TO DETERMINE RELATIONSHIP (35 TO 100 SAMPLES RECOMMENDED).

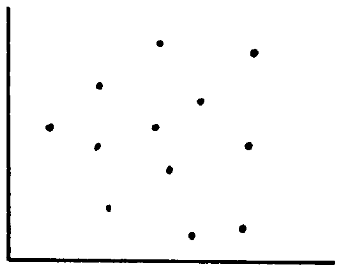
- DRAW AND LABEL THE HORIZONTAL AND VERTICAL AXES OF THE GRAPH. WE ARE GENERALLY CONCERNED WITH THE EFFECT THAT THE INDEPENDENT VARIABLE (HORIZONTAL AXIS) HAS ON THE DEPENDENT VARIABLE (VERTICAL AXIS).

- PLOT DATA ON THE GRAPH - LOCATING ONE VARIABLE ON THE VERTICAL SCALE AND THE OTHER ON THE HORIZONTAL.

- REVIEW PLOTTED POINTS TO ESTIMATE CORRELATION (FROM A POSITIVE TO NONE TO A NEGATIVE CORRELATION).

POSITIVE CORRELATION

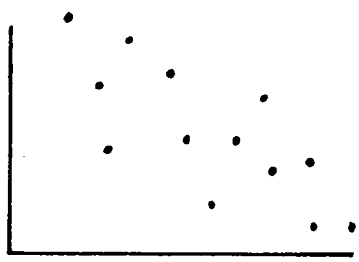




NO CORRELATION

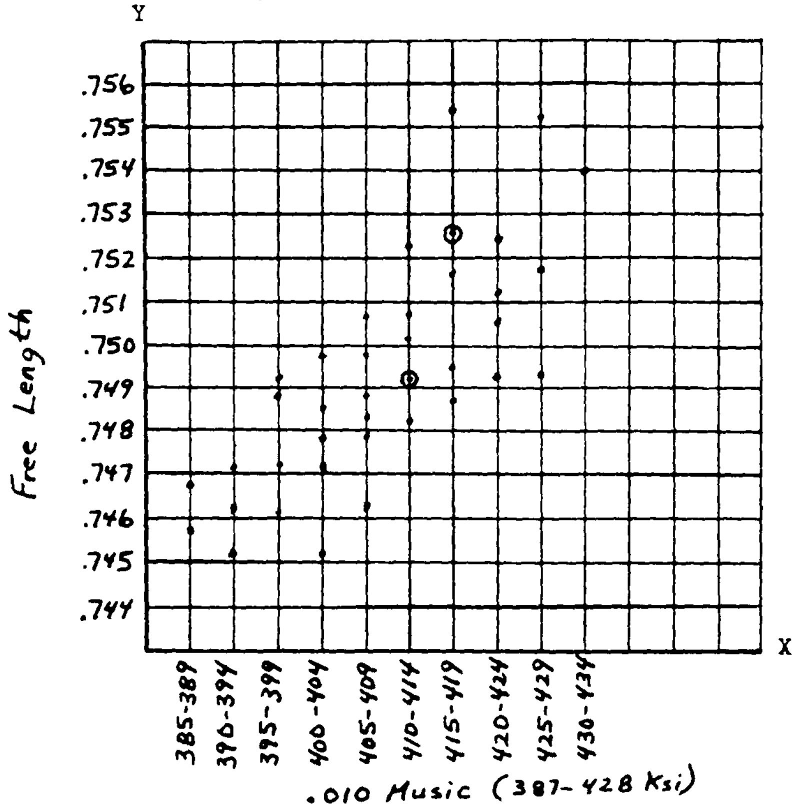
POSITIVE CORRELATION??

NEGATIVE CORRELATION



NEGATIVE CORRELATION??

SCATTER GRAPH



Note: Data is for illustrative purposes only.

	X	Y		X	Y		X	Y		X	Y		X	Y
1	397	.7472	21	418	.7518									
2	412	.7524	22	427	.7518									
3	402	.7499	23	402	.7473									
4	426	.7552	24	388	.7468									
5	393	.7471	25	411	.7492									
6	418	.7555	26	402	.7485									
7	405	.7483	27	428	.7494									
8	401	.7479	28	406	.7479									
9	422	.7525	29	421	.7493									
10	388	.7458	30	397	.7489									
11	418	.7527	31	406	.7507									
12	430	.7450	32	397	.7461									
13	406	.7499	33	408	.7463									
14	393	.7452	34	407	.7489									
15	412	.7508	35	418	.7527									
16	423	.7506	36	414	.7501									
17	411	.7492	37	422	.7512									
18	398	.7493	38	416	.7488									
19	392	.7463	39	412	.7482									
20	401	.7452	40	418	.7496									

CAUSE AND EFFECT DIAGRAM - A DIAGRAM OF THE VARIOUS PROCESS ELEMENTS USED TO ANALYZE THE POSSIBLE CAUSES THAT MAY AFFECT THE PROCESS VARIATION. THE DIAGRAM IS ALSO REFERRED TO AS THE FISH BONE CHART.

SUMMARY GUIDELINE (NOT A PROCEDURE):

- DETERMINE THE SUBJECT QUALITY CHARACTERISTIC FOR STUDY (USUALLY SELECTED FOR POSSIBLE IMPORVEMENT).

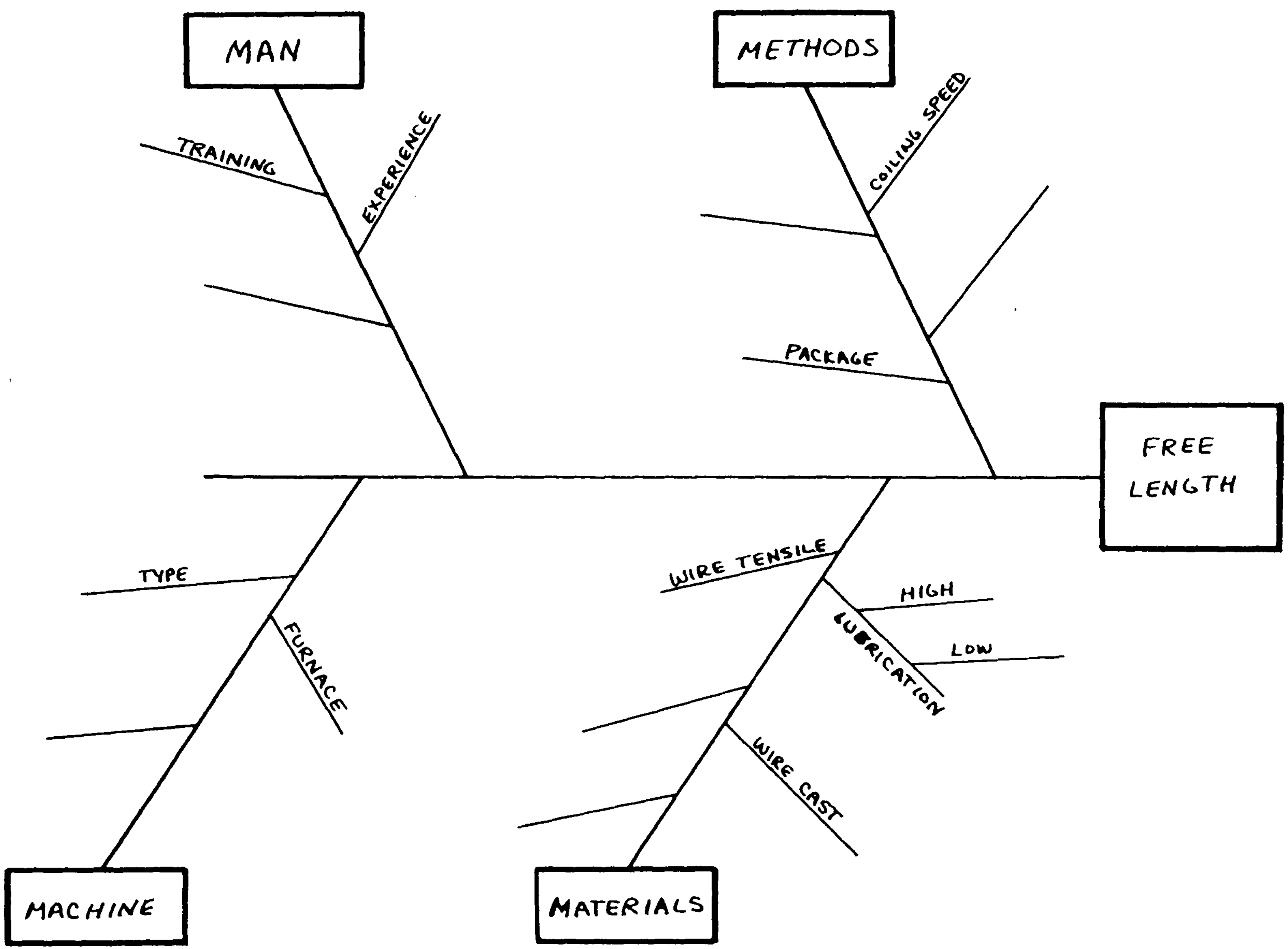
- WRITE SUBJECT CHARACTERISTIC IN RIGHTHAND BOX (FOR EXAMPLE, FREE LENGTH, LOAD, O.D., ETC.)

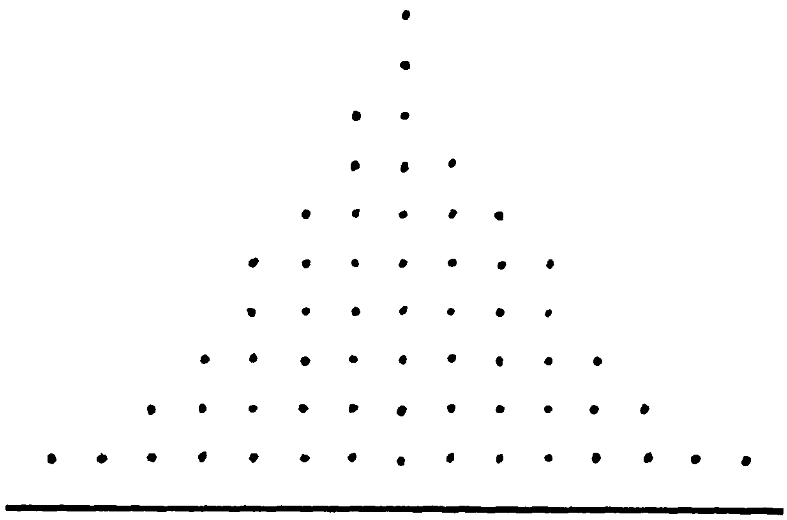
- DETERMINE MAIN FACTORS THAT MAY AFFECT THE SUBJECT CHARACTERISTIC. WRITE THESE ON THE BRANCHES THAT ARE FEEDING INTO THE MAIN LINE TO THE SUBJECT CHARACTERISTIC. GENERALLY, THE FOUR CATEGORIES OF MAIN FACTORS USUALLY INCLUDE MAN, MACHINES, METHODS, AND MATERIALS.

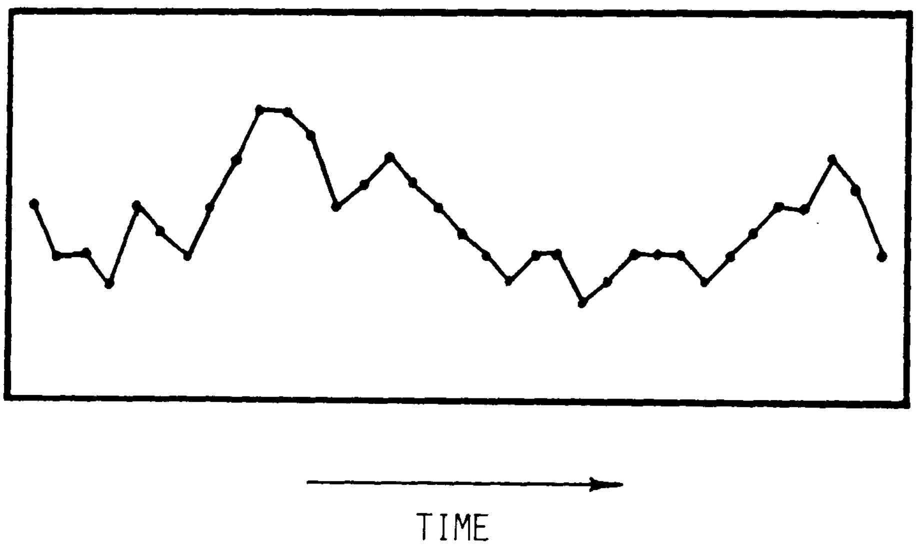
- ON EACH BRANCH WRITE IN THE MORE DETAILED FACTORS THAT MAY AFFECT (CAUSE VARIATION) FOR THE INDICATED MAIN CATEGORIES. EACH OF THE DETAILED BRANCHES MAY BE FURTHER BRANCHED WITH MORE DETAILED CAUSES.

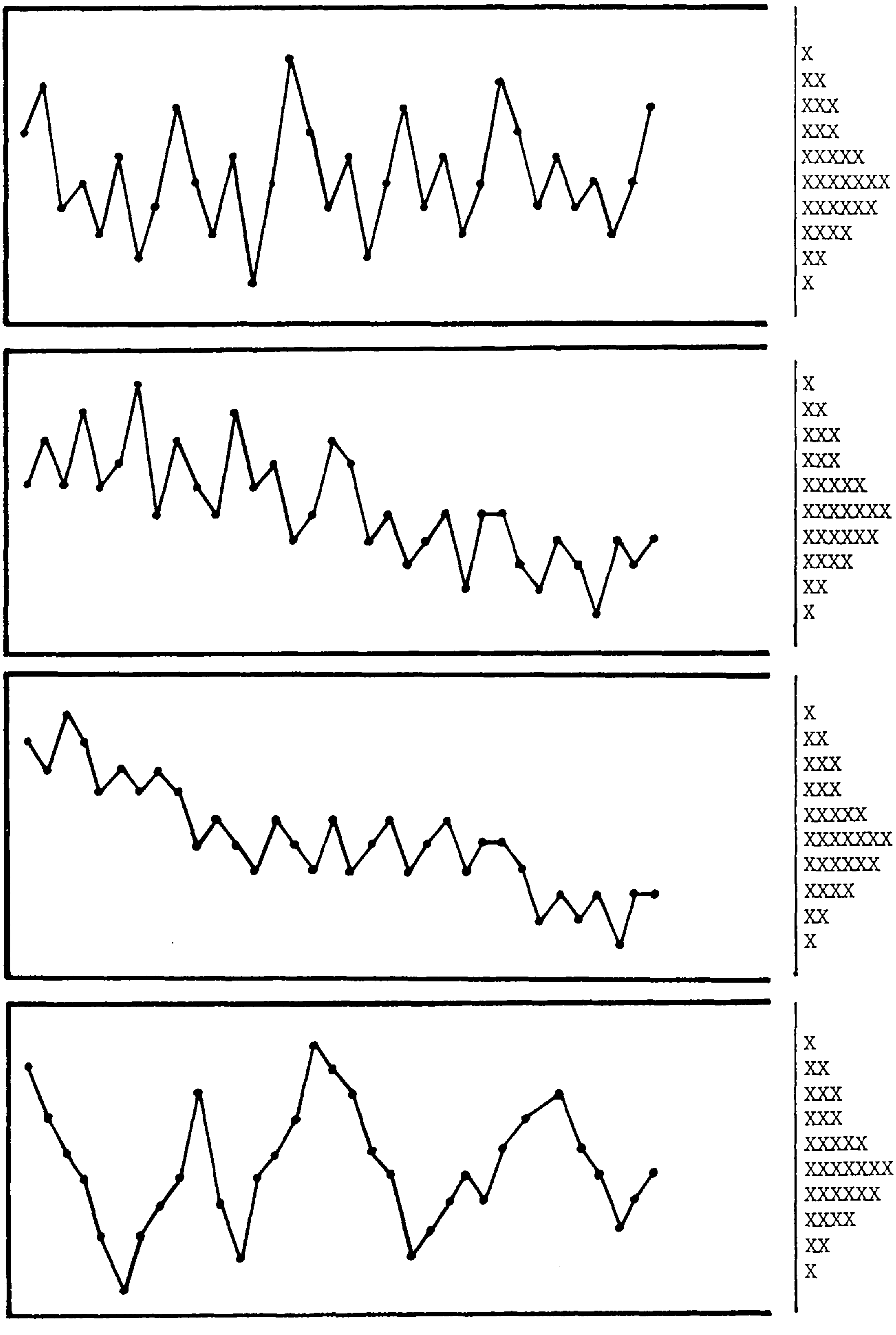
- REVIEW RELATIVE EFFECT OF EACH LISTED CAUSE AND REVIEW METHODS TO STUDY FOR THE IMPROVEMENT OF THE SUBJECT QUALITY CHARACTERISTIC.

CAUSE AND EFFECT DIAGRAM






TIME

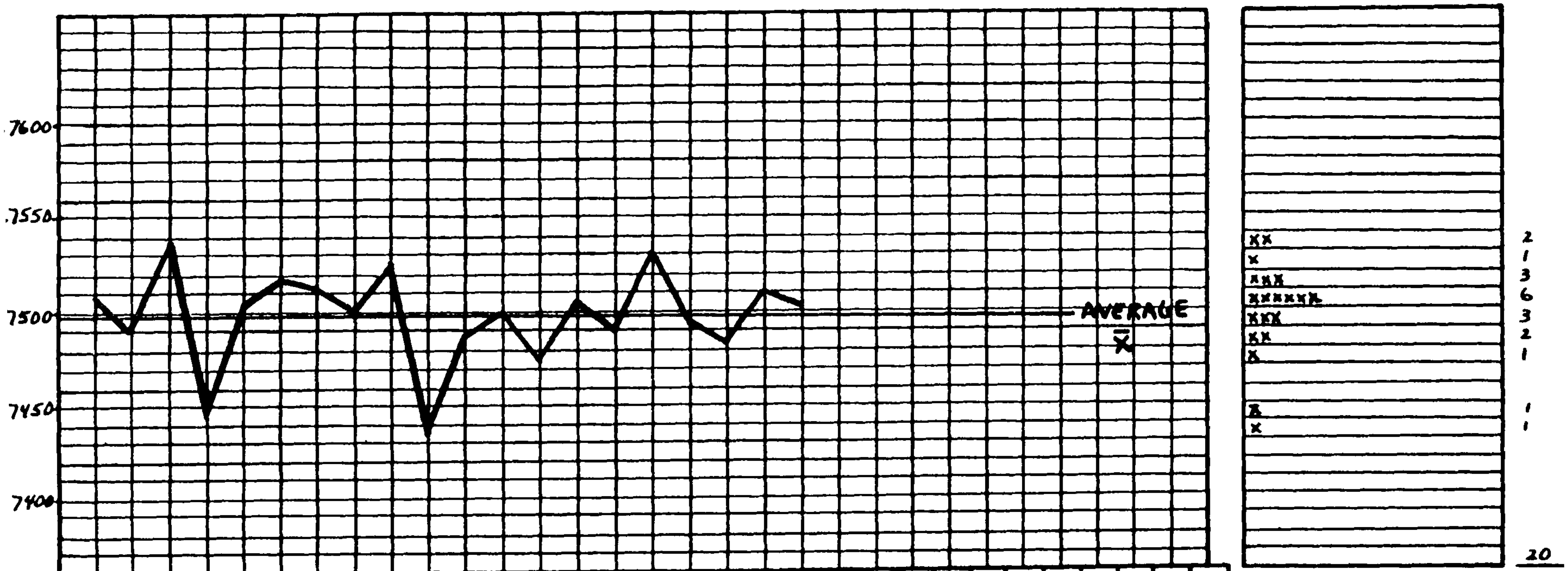


RUN CHART FOR INDIVIDUALS (X) - GRAPH OF INDIVIDUAL READINGS (MEASUREMENTS) VERSUS TIME TO REPRESENT POSSIBLE TRENDS.

SUMMARY GUIDELINE (NOT A PROCEDURE):

- SELECT CHARACTERISTIC OR VALUE TO PLOT.
- LABEL VERTICAL AND HORIZONTAL AXES. GENERALLY, VERTICAL IS SCALED VALUE AND HORIZONTAL AXIS IS TIME.
- COLLECT INDIVIDUAL DATA AND PLOT IN RESPECT TO THE VERTICAL AND HORIZONTAL AXES.
- CONNECT PLOTTED POINTS TO AID IN VISUALIZING ANY TRENDS.
- IF DESIRED, PLOT HISTOGRAM (TALLY) TO AID IN DESCRIBING THE DISTRIBUTION.
- CALCULATE AVERAGE VALUE TO AID IN DESCRIBING CENTER OF VALUES.
- REVIEW ANY TRENDS IN TIME SEQUENCE.

RUN CHART FOR INDIVIDUALS



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
x	.7508	.7490	.7536	.7448	.7504	.7518	.7512	.7501	.7526	.7436	.7488	.7500	.7474	.7504	.7490	.7530	.7492	.7484	.7510	.7502					

Average value ($\bar{X}$) = .74977

TWO CLASSIFICATIONS OF CONTROL CHARTS

° VARIABLES CHARTS

RUN
INDIVIDUALS WITH MOVING RANGE
MEDIAN
MEDIAN WITH MOVING RANGE
$\overline{X}$ AND R
$\overline{X}$ AND S
PRE-CONTROL

° ATTRIBUTES CHARTS

p
np
c
u

BENEFTIS OF USING CONTROL CHARTING:

° INCREASE COMMUNICATION BETWEEN SHIFTS, OPERATORS, CUSTOMERS, SUPPLIERS, ETC.

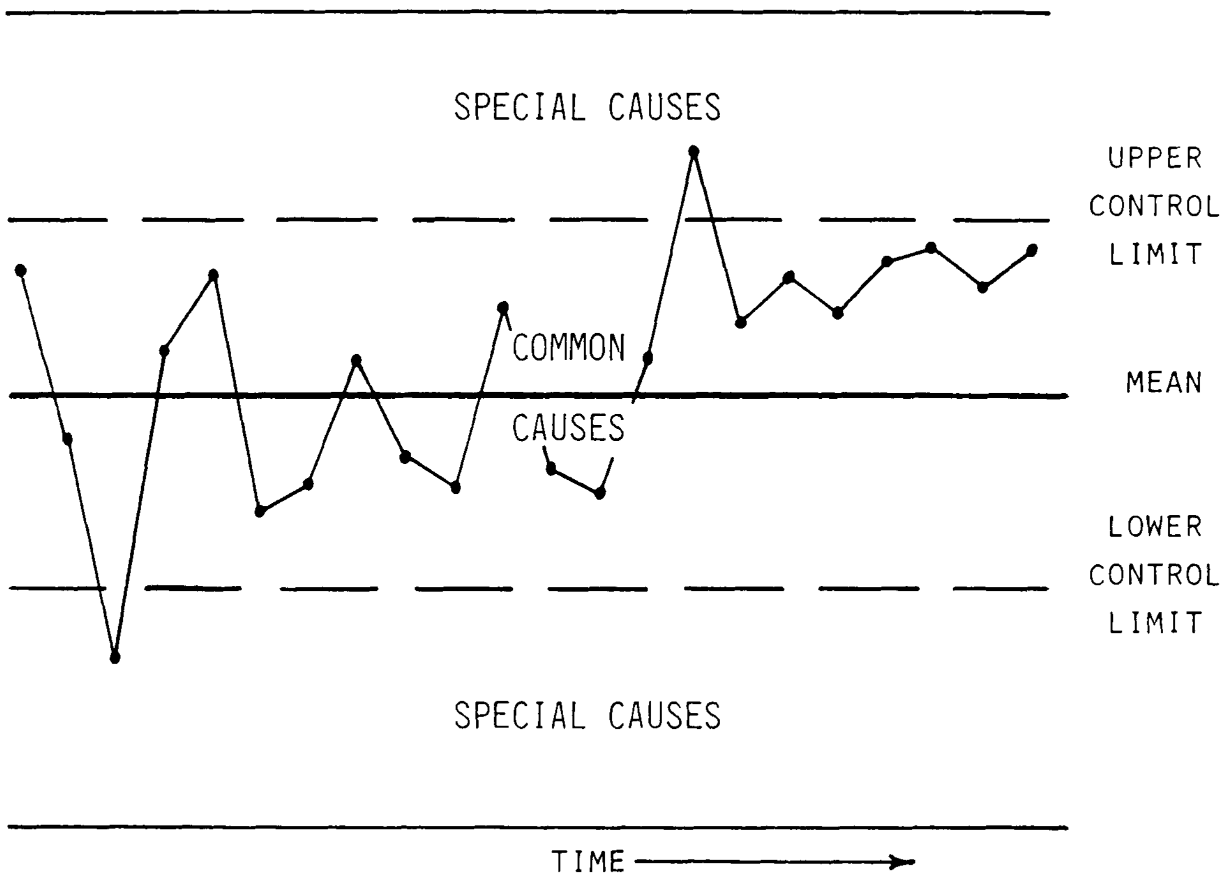
° PREDICT WHEN PROCESS OUT OF CONTROL.

° DETERMINE PROCESS CAPABILITY.

° ASSIST IN DETERMINING WHEN PROCESS ADJUSTMENTS ARE NECESSARY AND WHEN TO LEAVE PROCESS ALONE.

° RELATIVELY EASY METHOD TO MONITOR PROCESS VARIATION FOR COMMON AND SPECIAL CAUSES.

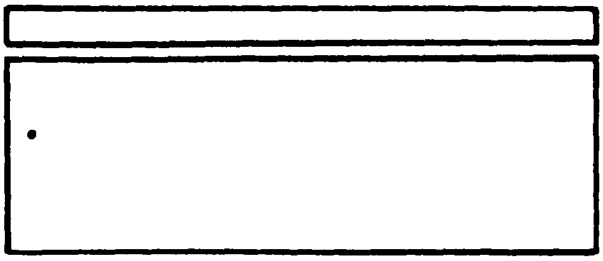
CONTROL CHART



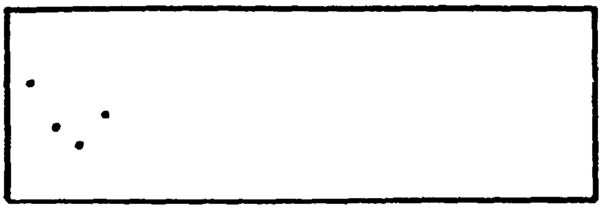
COMMON CAUSES - THE SOURCES OF <u>RANDOM</u> (INHERENT) VARIATION IN A PROCESS. POINTS PLOTTED ON A CONTROL CHART WILL FALL (ABOUT THE MEAN) WITHIN THE CALCULATED CONTROL LIMITS AND NOT IN A RUN OR OTHER NONRANDOM PATTERN.

SPECIAL CAUSES - THE SOURCES OF <u>NONRANDOM</u> (UNPREDICATABLE, UNSTABLE) VARIATION IN A PROCESS. IT IS GENERALLY INDICATED BY ONE OR MORE POINTS EXCEEDING THE CALCULATED CONTROL LIMITS. ALSO, IT MAY BE INDICATED BY POINTS WITHIN THE CONTROL LIMITS, BUT PLOTTED IN A RUN OR OTHER NONRANDOM PATTERN.

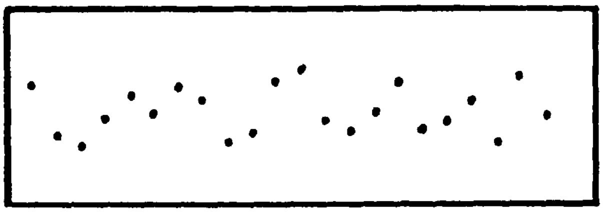
CONTROL CHART STEPS



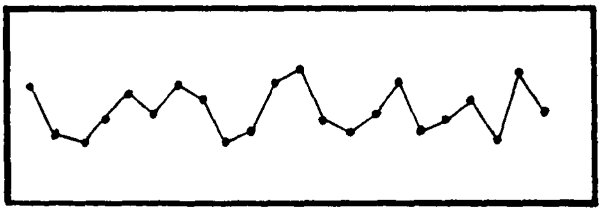
1. Select characteristic, sampling frequency, and complete information on chart.



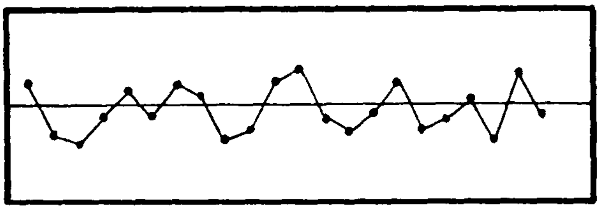
2. Collect data and plot. may also begin to calculate average, range, and/or standard deviation for each sample.



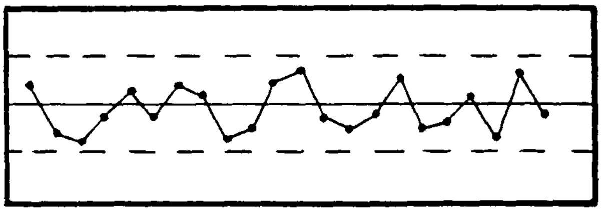
3. Continue plotting until have 20 to 25 points.



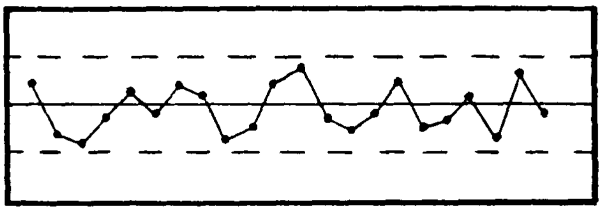
4. Connect plotted points for clarity.



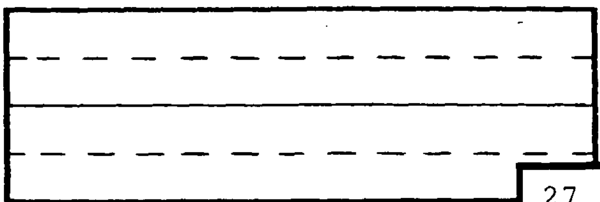
5. Calculate average and draw line.



6. Calculate control limits by using available formulas.



7. Interpret charts for control.



8. Continue to monitor process by continuing to plot (with calculated control limits).

INDIVIDUALS (X) AND MOVING RANGE CHART - A VARIABLES DATA TYPE OF CONTROL CHART THAT IS USED TO PLOT IN TIME SEQUENCE THE INDIVIDUAL OBSERVATIONS AND NOT SAMPLES OF MORE THAN ONE.

SUMMARY GUIDELINE (NOT A PROCEDURE):

- DETERMINE CHARACTERISTIC TO STUDY; FREQUENCY AND METHOD OF CHECKS; SAMPLING METHOD; AND SAMPLE SIZE IS ONE. COMPLETE HEADING ON CHART.
- SELECT MEASURING EQUIPMENT TO USE AND VERIFY THAT HAVE ADEQUATE GAGING.
- COLLECT AND RECORD THE INDIVIDUAL OBSERVATIONS. SELECT SCALES FOR CHART. THEN PLOT EACH OBSERVATION ON CHART. IF DESIRED, PLOT HISTOGRAM (TALLY) TO AID IN DESCRIBING THE DISTRIBUTION.
- CALCULATE MOVING RANGE BETWEEN THE INDIVIDUAL OBSERVATIONS WHICH IS THE DIFFERENCE BETWEEN SUCCESSIVE PAIRS OF RECORDED OBSERVATIONS. RECORD MOVING RANGE AND PLOT.
- CONTINUE UNTIL PLOT 15 TO 30 INDIVIDUAL OBSERVATIONS. CALCULATE THE AVERAGE OF THE OBSERVATIONS OR PROCESS AVERAGE ($\bar{X}$) AND, ALSO, THE AVERAGE OF THE MOVING RANGES ($\bar{R}$). THEN, PLOT (DRAW LINES) FOR $\bar{X}$ AND $\bar{R}$.
- CALCULATE THE CONTROL LIMITS FOR THE INDIVIDUAL OBSERVATIONS. $\bar{X}$ = AVERAGE OF INDIVIDUAL OBSERVATIONS. (REFER TO WORKBOOK APPENDIX FOR CONSTANTS):

$$UCL_X = \bar{X} + E_2\bar{R} \, *$$

$$LCL_X = \bar{X} - E_2\bar{R} \, *$$

- CALCULATE THE CONTROL LIMITS FOR THE MOVING RANGES (REFER TO WORKBOOK APPENDIX FOR CONSTANTS):

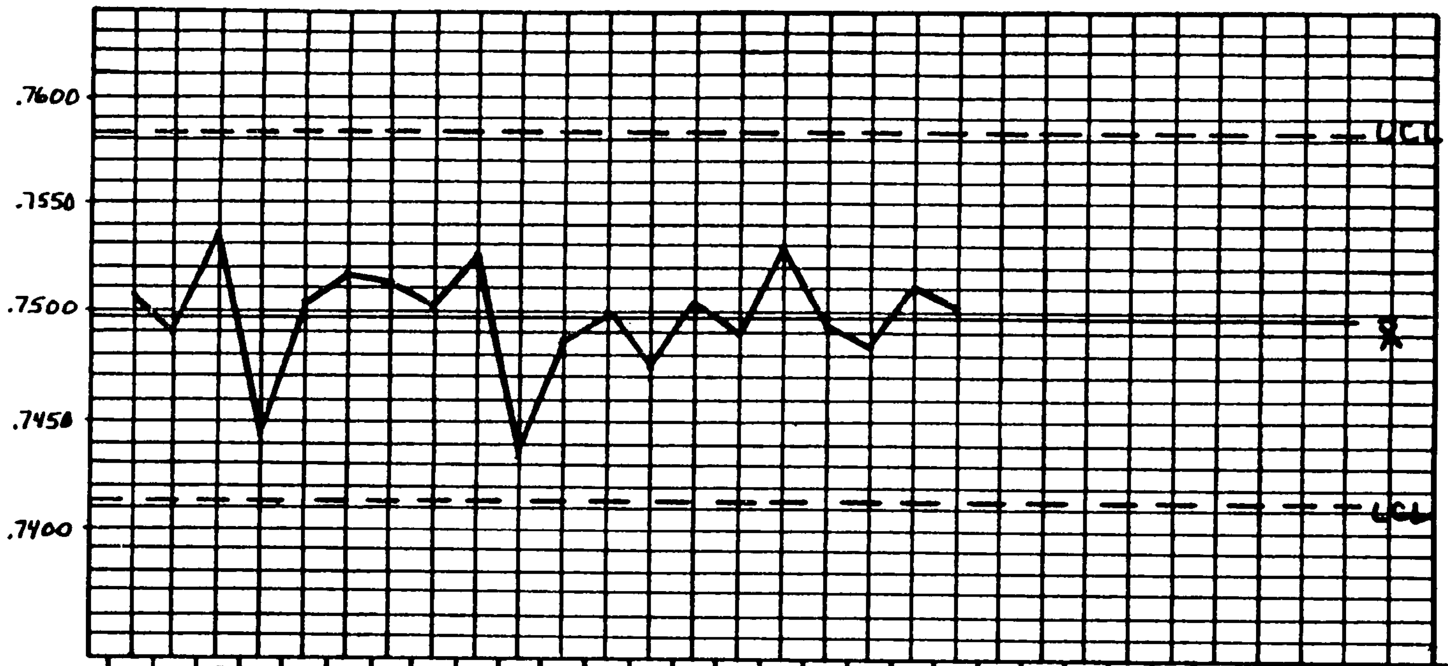
$$UCL_R = D_4\bar{R} \, *$$

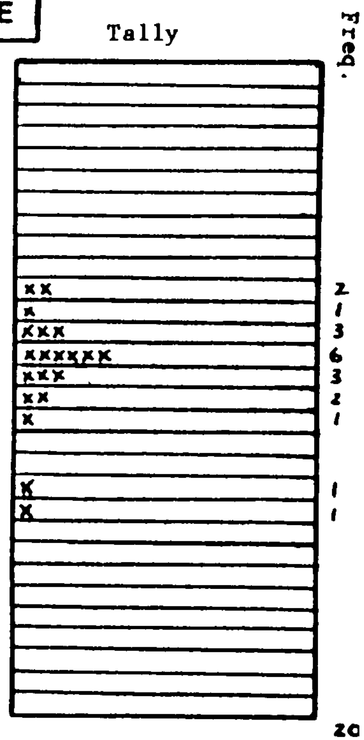
$$LCL_R = D_3\bar{R} \, *$$

  * CONSTANTS ARE SELECTED BASED UPON THE SIZE USED FOR GROUPING RANGES. (USUALLY N = 2 WHEN USE SUCCESSIVE PAIRS).

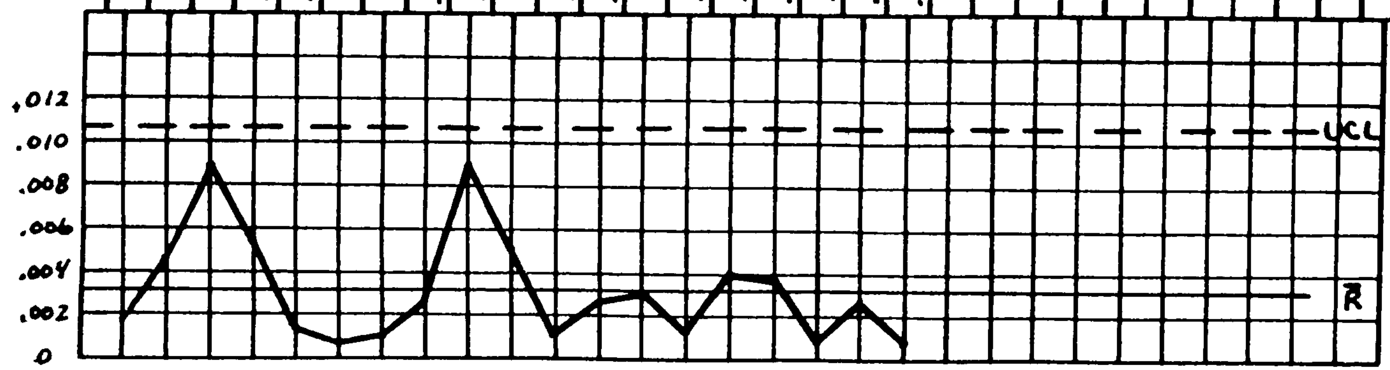
- PLOT (DRAW DASH LINES) FOR THE INDIVIDUAL AND MOVING RANGE CONTROL LIMITS.
- REVIEW CHART (ACTUALLY TWO CHARTS THAT SHOULD BE REVIEWED TOGETHER) FOR CONTROL AND CAPABILITY.
- CONTINUE TAKING SAMPLES AND PLOTTING TO MAINTAIN CONTROL.

RUN CHART FOR INDIVIDUALS WITH MOVING RANGE





	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
X	.7508	.7490	.7536	.7448	.7504	.7518	.7512	.7502	.7526	.7436	.7488	.7500	.7474	.7504	.7490	.7530	.7492	.7484	.7510	.7502					
Moving Range		.0018	.0046	.0088	.0056	.0014	.0006	.0010	.0024	.0090	.0052	.0012	.0026	.0030	.0014	.0040	.0038	.0008	.0026	.0008					



Average value ($\bar{X}$) .74977

Average range ($\bar{R}$) .00319

UCL_X = .75826

LCL_X = .74128

UCL_R = .01042

LCL_R = 0

MEDIAN CHART - A VARIABLES DATA TYPE OF CONTROL CHART THAT IS USED TO PLOT THE MEDIAN VALUES OF SAMPLES (SUBGROUPS).

SUMMARY GUIDELINE (NOT A PROCEDURE):

- DETERMINE CHARACTERISTIC TO STUDY; FREQUENCY AND METHOD OF CHECKS; SAMPLING METHOD; AND SAMPLE SIZE (USUALLY INCLUDES LESS THAN 10 OBSERVATIONS PER SAMPLE AND, IF POSSIBLE, AN ODD NUMBERED SAMPLE SIZE - FOR EXAMPLE, 5). COMPLETE HEADING ON CHART.

- SELECT MEASURING EQUIPMENT TO USE AND VERIFY THAT HAVE ADEQUATE GAGING.

- COLLECT AND RECORD THE INDIVIDUAL OBSERVATIONS FOR EACH SAMPLE. SELECT ADEQUATELY LARGE SCALES FOR THE CHART. THEN, PLOT EACH OBSERVATION OF SAMPLE ON THE CHART. (FOR EXAMPLE, USE A DOT FOR THE MEASUREMENT AND AN "X" FOR THE SAME VALUE IN THE SAMPLE.) CIRCLE THE MEDIAN VALUE IN THE SAMPLE.

- CONTINUE UNTIL PLOT 20 TO 30 SAMPLES. CALCULATE THE AVERAGE OF THE SAMPLE MEDIANS ($\bar{\tilde{X}}$) AND AVERAGE OF THE SAMPLE RANGES ($\bar{R}$). THEN, PLOT (DRAW LINE) FOR $\bar{\tilde{X}}$ AND $\bar{R}$.

- CALCULATE THE CONTROL LIMITS FOR THE SAMPLE AVERAGE MEDIANS (REFER TO WORKBOOK APPENDIX FOR CONSTANTS):

$$UCL_{\tilde{X}} = \bar{\tilde{X}} + \tilde{A}_2\bar{R}$$
$$LCL_{\tilde{X}} = \bar{\tilde{X}} - \tilde{A}_2\bar{R}$$

- CALCULATE THE CONTROL LIMITS FOR THE SAMPLE RANGES (REFER TO WORKBOOK APPENDIX FOR CONSTANTS):

$$UCL_R = D_4\bar{R} \; *$$
$$LCL_R = D_3\bar{R} \; *$$

  *SOME FORMULAS USE $\tilde{D}_3$ AND $\tilde{D}_4$. CONTACT YOUR CUSTOMER FOR SPECIFIC REQUIREMENTS.

- PLOT (DRAW DASH LINES) FOR THE MEDIAN AND RANGE CONTROL LIMITS.

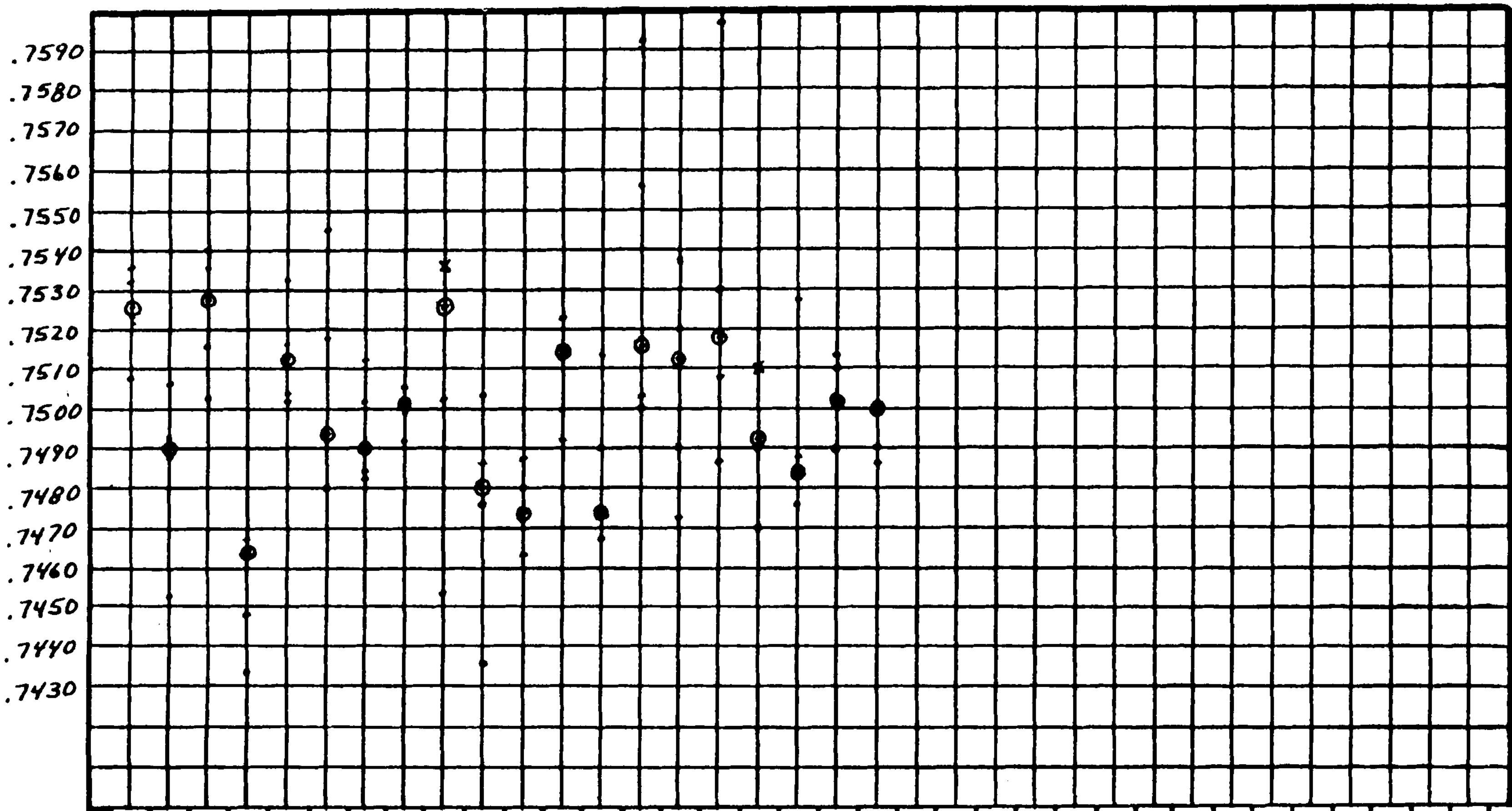
- REVIEW MEDIAN CHART (ACTUALLY TWO CHARTS THAT SHOULD BE REVIEWED TOGETHER) FOR CONTROL AND CAPABILITY.

- CONTINUE TAKING SAMPLES AND PLOTTING TO MAINTAIN CONTROL.

MEDIAN CHART - OPERATION

Part # AEC-5490 Compression
Operation # Coiling
Machine # 23

Characteristic: Free Length .750 ±.010
Sample Size/Frequency: Sample of 5/4 Samples per Hour



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Median Value $\tilde{X}$	.7526	.7490	.7528	.7464	.7512	.7494	.7490	.7502	.7526	.7480	.7474	.7514	.7474	.7516	.7512	.7518	.7492	.7484	.7502	.7500					
Range (not required)																									

MEDIAN CHART - ANALYSIS

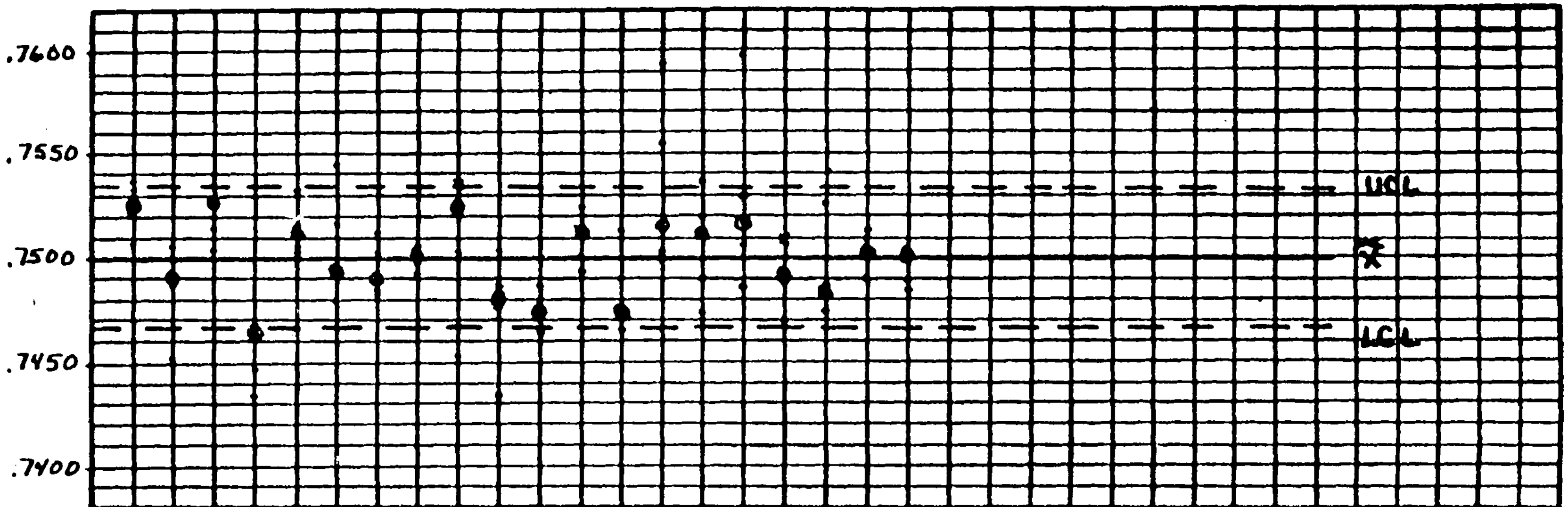
Part # AEC-5490 Compression
Operation Coil
Machine # 23
Dimension .750 ±.010 Free Length
Frequency: 4/Hour   Sample size: 5

UCL $_{\tilde{X}} = \bar{\tilde{X}} + \bar{A}_2 \bar{R}$ $.74999 + (.691 \times .00472) = .75325$

LCL $_{\tilde{X}} = \bar{\tilde{X}} - \bar{A}_2 \bar{R}$ $.74999 - (.691 \times .00472) = .74673$

UCL $_R = D_4 \bar{R}$ $2.114 \times .00472 = .00998$

LCL $_R = D_3 \bar{R}$ $0 \times .00472 = 0$



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Median	.7526	.7490	.7528	.7464	.7512	.7494	.7490	.7502	.7526	.7480	.7474	.7514	.7474	.7516	.7512	.7518	.7492	.7484	.7502	.7500				
Range	.0028	.0054	.0036	.0034	.0030	.0066	.0030	.0014	.0082	.0068	.0024	.0032	.0046	.0092	.0064	.0112	.0040	.0052	.0024	.0016				

Ave. Median
$\bar{\tilde{X}}$ = .74999

Ave. Range
$\bar{R}$ = .00472

$\bar{X}$ & R CHART - ACTUALLY TWO CHARTS PLOTTED VERSUS TIME. $\bar{X}$ IS THE AVERAGE OF EACH RESPECTIVE SAMPLE (SUBGROUP) THAT IS BEING PLOTTED; R IS THE RANGE OF EACH RESPECTIVE SAMPLE (SUBGROUP) THAT IS BEING PLOTTED.

SUMMARY GUIDELINE (NOT A PROCEDURE):

- DETERMINE CHARACTERISTIC TO STUDY; FREQUENCY AND METHOD OF CHECKS; SAMPLING METHOD; AND SAMPLE SIZE (USUALLY INCLUDES MORE THAN ONE OBSERVATION —3 TO 5 OBSERVATIONS PER SAMPLE). COMPLETE HEADING ON CHART.

- SELECT MEASURING EQUIPMENT TO USE AND VERIFY THAT HAVE ADEQUATE GAGES.

- COLLECT AND RECORD INDIVIDUAL OBSERVATIONS AND CALCULATE THE AVERAGE ($\bar{X}$) AND RANGE (R) FOR EACH SAMPLE. DETERMINE CHART SCALES AND PLOT EACH SAMPLE AVERAGE AND RANGE ON CHART.

- CONTINUE UNTIL PLOT 20 TO 30 SAMPLES. CALCULATE THE AVERAGE OF THE AVERAGES ($\bar{\bar{X}}$) AND THE AVERAGE OF THE RANGES ($\bar{R}$). THEN, PLOT (DRAW LINE) FOR $\bar{\bar{X}}$ AND $\bar{R}$.

- CALCULATE THE CONTROL LIMITS FOR THE SAMPLE AVERAGES (REFER TO WORKBOOK APPENDIX FOR CONSTANTS):

$$UCL_{\bar{X}} = \bar{\bar{X}} + A_2\bar{R}$$

$$LCL_{\bar{X}} = \bar{\bar{X}} - A_2\bar{R}$$

- CALCULATE THE CONTROL LIMITS FOR THE SAMPLE RANGES (REFER TO WORKBOOK APPENDIX FOR CONSTANTS):

$$UCL_R = D_4\bar{R}$$

$$LCL_R = D_3\bar{R}$$

- PLOT (DRAW DASH LINES) FOR THE AVERAGE ($\bar{X}$) AND RANGE (R) CONTROL LIMITS.

- REVIEW $\bar{X}$ AND R CHART (ACTUALLY TWO CHARTS THAT SHOULD BE REVIEWED TOGETHER) FOR CONTROL AND CAPABILITY.

- CONTINUE TAKING SAMPLES AND PLOTTING TO MAINTAIN CONTROL.

PART # *AEC-5490*

AVERAGE AND RANGE ($\bar{X}$-R) CHART

OPERATION/MACHINE: *Coiling #23*

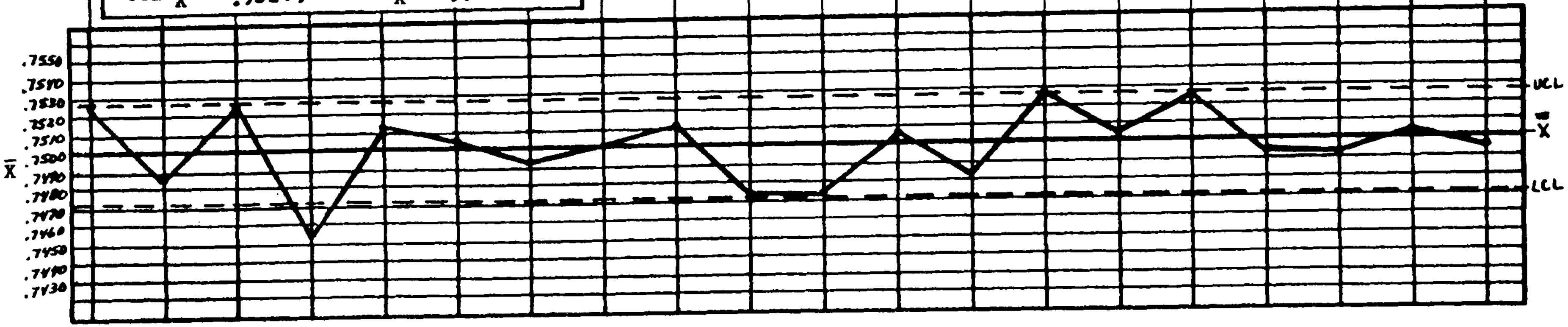
4/20

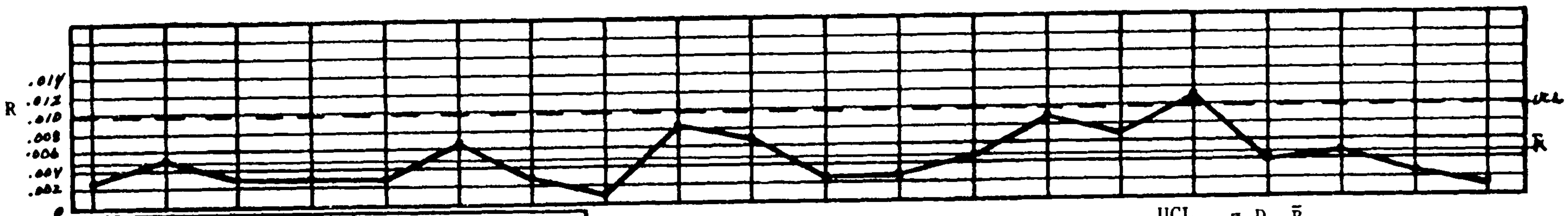
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	.7508	.7490	.7536	.7448	.7504	.7518	.7512	.7502	.7526	.7436	.7488	.7500	.7474	.7504	.7490	.7530	.7492	.7484	.7510	.7502
	.7524	.7494	.7516	.7468	.7502	.7480	.7490	.7506	.7536	.7504	.7472	.7492	.7468	.7516	.7538	.7518	.7510	.7476	.7490	.7500
	.7536	.7488	.7540	.7434	.7516	.7492	.7482	.7500	.7536	.7476	.7480	.7524	.7514	.7500	.7474	.7508	.7510	.7484	.7502	.7490
	.7532	.7506	.7528	.7464	.7532	.7494	.7502	.7502	.7454	.7480	.7474	.7514	.7490	.7592	.7512	.7598	.7490	.7528	.7502	.7500
	.7526	.7452	.7504	.7464	.7512	.7546	.7484	.7492	.7502	.7486	.7464	.7514	.7474	.7536	.7520	.7486	.7470	.7488	.7514	.7486
Tot.	3.7626	3.7430	3.7624	3.7278	3.7566	3.7530	3.7470	3.7502	3.7554	3.7382	3.7378	3.7544	3.7420	3.7648	3.7534	3.7640	3.7472	3.7460	3.7518	3.7478
$\bar{X}$	.75252	.74860	.75248	.74556	.75132	.75060	.74940	.75004	.75108	.74764	.74756	.75088	.74840	.75296	.75068	.75280	.74944	.74920	.75036	.74956
R	.0028	.0054	.0036	.0034	.0030	.0066	.0030	.0014	.0082	.0068	.0024	.0032	.0046	.0092	.0064	.0112	.0040	.0052	.0024	.0016

$\bar{\bar{X}}$ = .75005

$\bar{R}$ = .00472

UCL $\bar{X}$ = .75279 LCL $\bar{X}$ = .74732





UCL $_R$ = .00996 LCL $_R$ = 0

$UCL_{\bar{X}} = \bar{\bar{X}} + A_2 \bar{R}$

$LCL_{\bar{X}} = \bar{\bar{X}} - A_2 \bar{R}$

$UCL_R = D_4 \bar{R}$

$LCL_R = D_3 \bar{R}$

CONTROL CHART - OPERATION

Part # AEC-5490

Operation Coiling Free Length .750 ±.010

Machine # 23

Sample size = 5

Frequency: 4/Hour

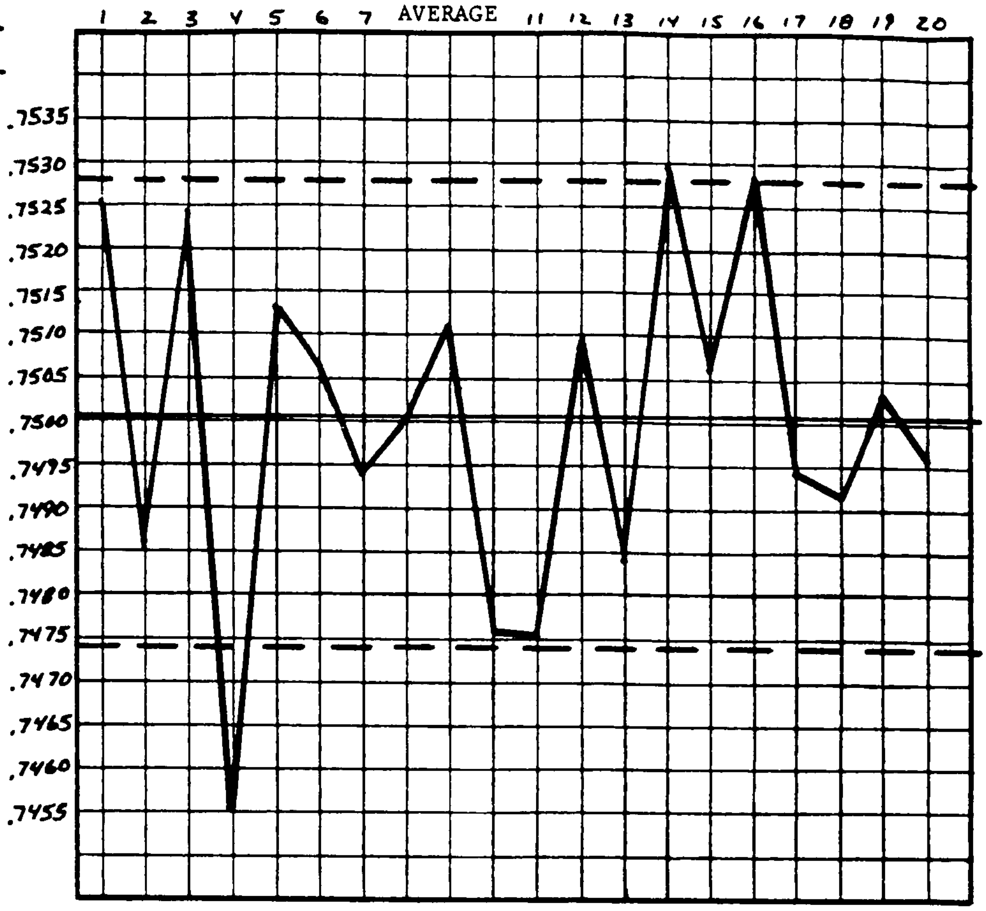
	$\bar{X}$	R
1	.75252	.0028
2	.74860	.0054
3	.75248	.0036
4	.74556	.0034
5	.75132	.0030
6	.75060	.0066
7	.74940	.0030
8	.75004	.0014
9	.75108	.0082
10	.74764	.0068
11	.74756	.0024
12	.75088	.0032
13	.74840	.0046
14	.75296	.0092
15	.75068	.0064
16	.75280	.0112
17	.74944	.0040
18	.74920	.0052
19	.75036	.0024
20	.74956	.0016
$\bar{\bar{X}}$=	.75005	
$\bar{R}$=		.00472

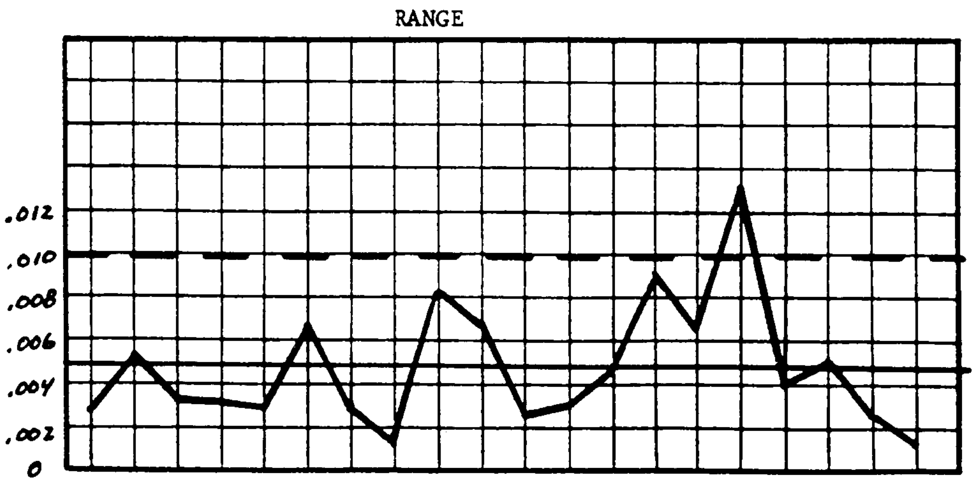
UCL $\bar{X}$ .75277

LCL $\bar{X}$ .74732

LCL R .00996

LCL R 0

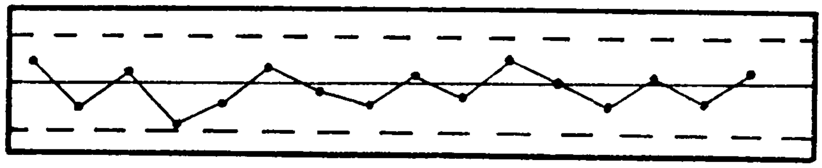




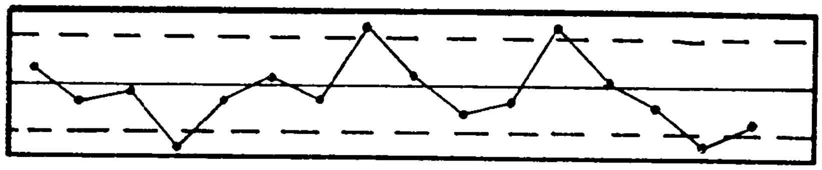
CONTROL CHART INTERPRETATIONS

- IDENTIFY EXISTENCE OF COMMON AND SPECIAL CAUSES
- IDENTIFY PROCESS TRENDS
- IDENTIFY WHEN TO INITIATE CORRECTIVE ACTION OR NOT

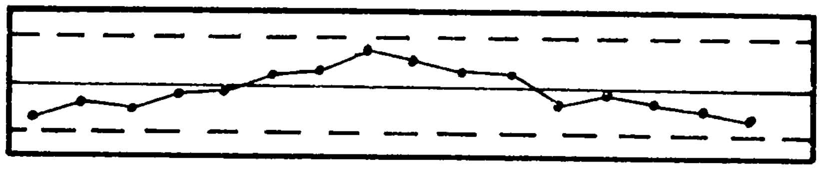
NATURAL PATTERN



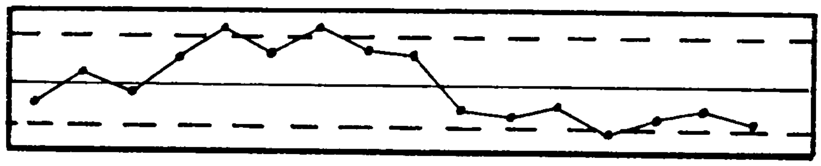
POINTS OUTSIDE CONTROL LIMITS



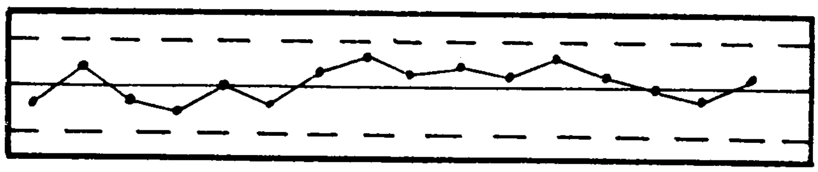
TRENDS (UPWARD OR DOWNWARD)



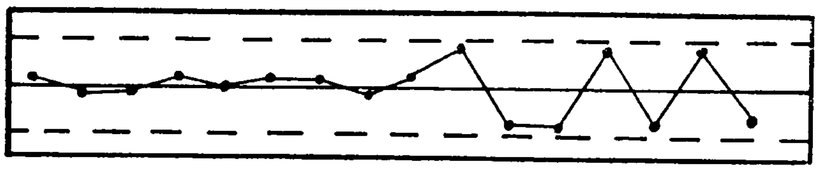
PROCESS SHIFT (UPWARD OR DOWNWARD)



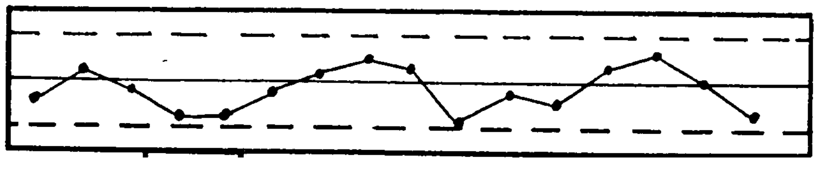
RUN



NARROW OR WIDE VARIATION



REPETITIVE CYCLE



$\overline{X}$ & S CHART - ACTUALLY TWO CHARTS PLOTTED VERSUS TIME: $\overline{X}$ IS THE AVERAGE OF EACH RESPECTIVE SAMPLE (SUBGROUP) THAT IS BEING PLOTTED; S IS THE STANDARD DEVIATION OF EACH RESPECTIVE SAMPLE (SUBGROUP) THAT IS BEING PLOTTED.

SUMMARY GUIDELINE (NOT A PROCEDURE):

- DETERMINE CHARACTERISTIC TO STUDY; FREQUENCY AND METHODS OF CHECKS; SAMPLING METHOD; AND SAMPLE SIZE (USUALLY INCLUDES SUBGROUPS OF OVER 5 OBSERVATIONS PER SAMPLE). COMPLETE HEADING ON CHART.

- SELECT MEASURING EQUIPMENT TO USE AND VERIFY THAT HAVE ADEQUATE GAGES.

- COLLECT AND RECORD INDIVIDUAL OBSERVATIONS AND CALCULATE THE AVERAGE ($\overline{X}$) AND STANDARD DEVIATION (S) FOR EACH SAMPLE. DETERMINE CHART SCALES AND PLOT EACH SAMPLE AVERAGE AND STANDARD DEVIATION.

- CONTINUE UNTIL PLOT 20 TO 30 SAMPLES. CALCULATE THE AVERAGE OF THE AVERAGES ($\overline{\overline{X}}$) AND THE AVERAGE OF THE STANDARD DEVIATIONS ($\overline{S}$). THEN, PLOT (DRAW LINE) FOR $\overline{\overline{X}}$ AND $\overline{S}$.

- CALCULATE THE CONTROL LIMITS FOR THE SAMPLE AVERAGES (REFER TO WORKBOOK APPENDIX FOR CONSTANTS):

$$UCL_{\overline{X}} = \overline{\overline{X}} + A_3\overline{S}$$

$$LCL_{\overline{X}} = \overline{\overline{X}} - A_3\overline{S}$$

- CALCULATE THE CONTROL LIMITS FOR THE SAMPLE STANDARD DEVIATIONS (REFER TO WORKBOOK APPENDIX FOR CONSTANTS):

$$UCL_S = B_4\overline{S}$$

$$LCL_S = B_3\overline{S}$$

- PLOT (DRAW DASH LINES) FOR THE AVERAGE ($\overline{X}$) AND STANDARD DEVIATION (S) CONTROL LIMITS.

- REVIEW $\overline{X}$ AND S CHART (ACTUALLY TWO CHARTS THAT SHOULD BE REVIEWED TOGETHER) FOR CONTROL AND CAPABILITY.

- CONTINUE TAKING SAMPLES AND PLOTTING TO MAINTAIN CONTROL.

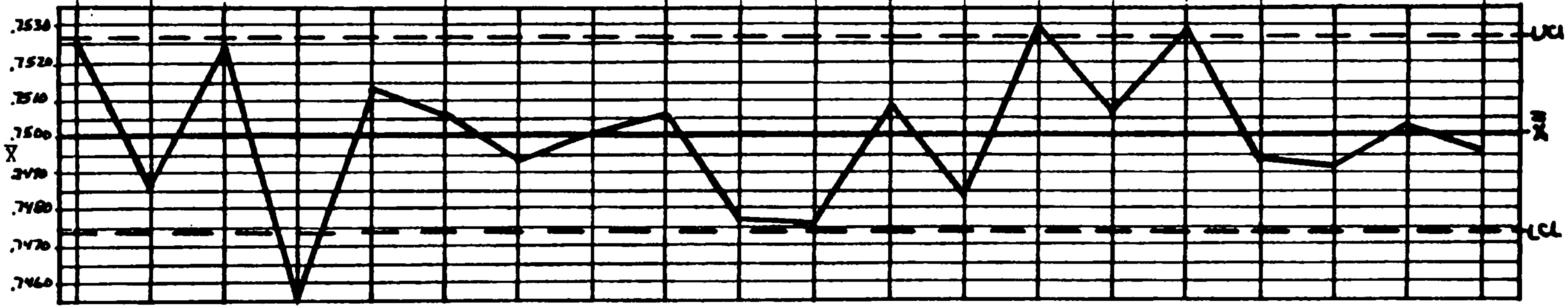
Part # *AEC - 5490*
Free Length .750 ± .010

AVERAGE & STANDARD DEVIATION ($\bar{X}$ - s) CHART

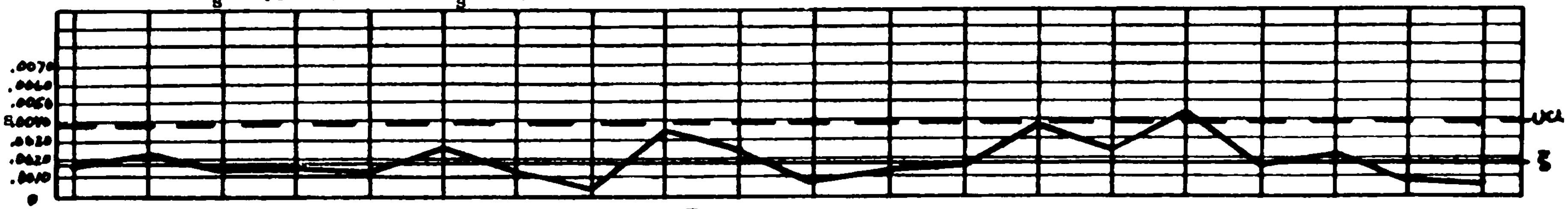
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	.7508	.7490	.7536	.7448	.7504	.7518	.7512	.7502	.7526	.7436	.7488	.7500	.7474	.7504	.7490	.7530	.7492	.7484	.7510	.7502
	.7524	.7494	.7516	.7468	.7502	.7480	.7490	.7506	.7536	.7504	.7472	.7492	.7468	.7516	.7538	.7518	.7510	.7476	.7490	.7500
	.7536	.7488	.7540	.7434	.7516	.7492	.7482	.7500	.7536	.7476	.7480	.7524	.7514	.7500	.7474	.7508	.7510	.7484	.7502	.7490
	.7532	.7506	.7528	.7464	.7532	.7494	.7502	.7502	.7454	.7480	.7474	.7514	.7490	.7592	.7512	.7598	.7490	.7528	.7502	.7500
	.7526	.7452	.7504	.7464	.7512	.7546	.7484	.7492	.7502	.7486	.7464	.7514	.7474	.7536	.7520	.7486	.7470	.7488	.7514	.7486
Total	3.7626	3.7430	3.7624	3.7278	3.7566	3.7530	3.7470	3.7502	3.7554	3.7382	3.7378	3.7544	3.7420	3.7648	3.7534	3.7640	3.7472	3.7460	3.7518	3.7478
$\bar{X}$	.75252	.74860	.75248	.74556	.75132	.75060	.74940	.75004	.75108	.74764	.74756	.75088	.74840	.75296	.75068	.75280	.74944	.74920	.75036	.74956
s	.00107	.00202	.00148	.00143	.00120	.00263	.00127	.00052	.00347	.00250	.00090	.00127	.00187	.00376	.00252	.00423	.00166	.00206	.00092	.00071

Note: Sample sizes are normally more than 5 for an $\bar{X}$-s chart.

$UCL_{\bar{X}}$ = .75269 $LCL_{\bar{X}}$ = .74735 $\bar{\bar{X}}$ = .75005 $\bar{s}$ = .00187



UCL_s = .00391 LCL_s = 0



Operation: *Coiling*

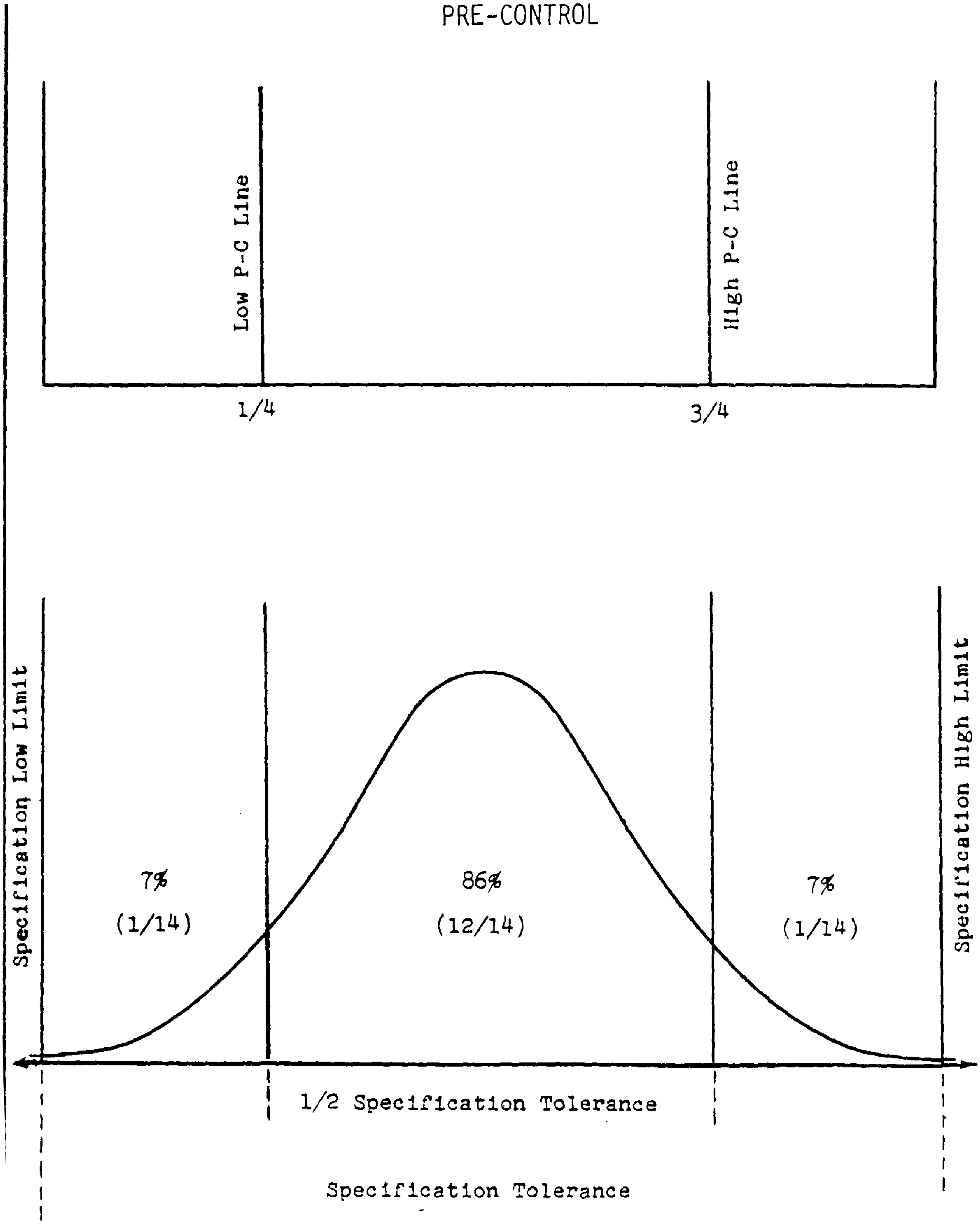
Machine # *23*

$UCL_{\bar{X}} = \bar{\bar{X}} + A_3 \bar{R}$

$LCL_{\bar{X}} = \bar{\bar{X}} - A_3 \bar{R}$

$UCL_s = B_4 \bar{s}$

$LCL_s = B_3 \bar{s}$

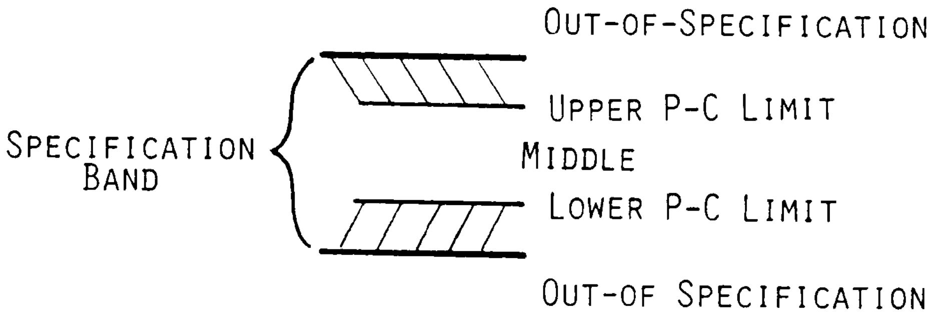

PRE-CONTROL
Low P-C Line
High P-C Line
1/4
3/4
Specification Low Limit
Specification High Limit
7%
(1/14)
86%
(12/14)
7%
(1/14)
1/2 Specification Tolerance
Specification Tolerance

PRE-CONTROL CHART - A CONTROL CHART TECHNIQUE THAT IS USED FOR MONITORING A PROCESS BY TAKING MEASUREMENTS AT SPECIFIED INTERVALS AND PLOTTING MIDDLE, UPPER/LOWER LIMIT, AND OUT-OF-SPECIFICATION ZONES. GENERALLY, THIS TECHNIQUE IS USED FOR A PROCESS IN CONTROL AND CENTERED WITHIN THE SPECIFICATION RANGE.

SUMMARY GUIDELINE (NOT A PROCEDURE):

° DETERMINE CHARACTERISTIC TO STUDY. COMPLETE HEADING ON CHART.

° DIVIDE THE CHARACTERISTIC'S SPECIFICATION BAND IN FOUR EQUAL VALUES. INDICATE ON THE CHART AS FOLLOWS:



° BEGIN PROCESS AND PLOT WITHING THE APPROPRIATE SQUARES AS FOLLOWS IN A TYPICAL PROCEDURE:

1. SET UP PROCESS AT CENTER OF SPECIFICATION.

2. CHECK PROCESS:

   - IF FIRST MEASUREMENT IS OUTSIDE SPECIFICATION, ADJUST.

   - IF FIRST MEASUREMENT IS WITHIN SPECIFICATION, BUT OUTSIDE OF P-C LIMITS, PERFORM ANOTHER CHECK.

     -- IF MEASUREMENT IS IN SAME ZONE, ADJUST PROCESS IN REQUIRED DIRECTION.

     -- IF MEASUREMENT IS IN OPPOSITE ZONE, AN "OUT-OF-CONTROL" CONDITION MAY EXIST.

     -- IF MEASUREMENT IS IN MIDDLE ZONE, TAKE ANOTHER MEASUREMENT.

   - CONTINUE CHECKS UNTIL FIVE CONSECUTIVE MEASUREMENTS ARE IN THE MIDDLE ZONE.

3. AFTER FIVE CONSECUTIVE MEASUREMENTS ARE WITHIN THE MIDDLE ZONE, PROCESS IS CONSIDERED IN CONTROL AND ONLY PERIODIC CHECKS ARE REQUIRED (AS IS PRACTICAL).

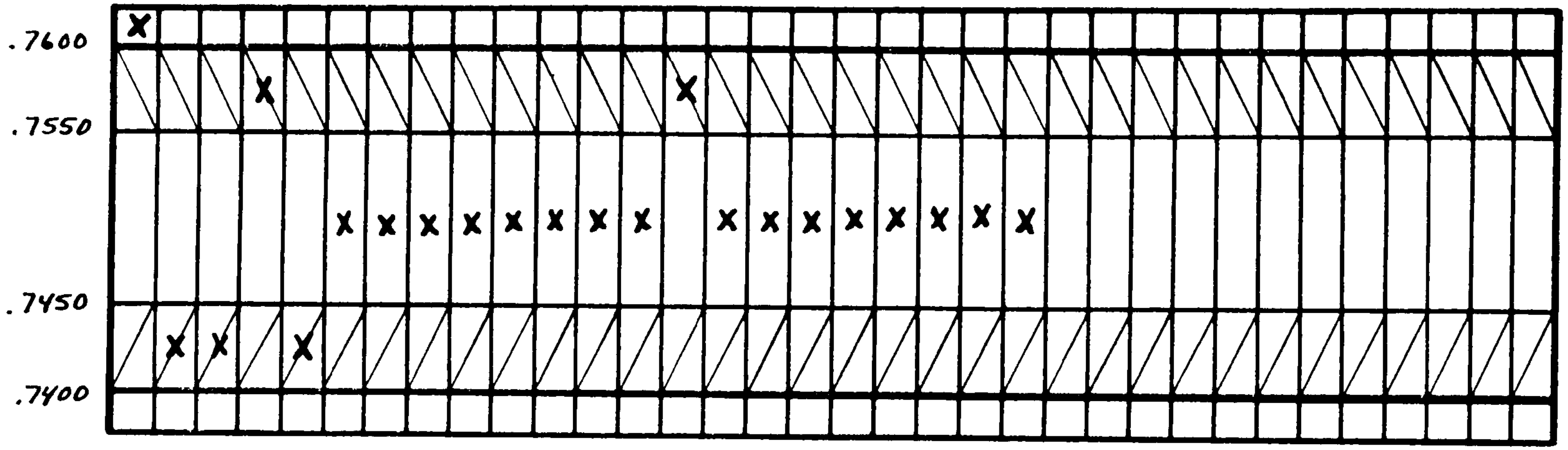
   - PERIODIC CHECKS CONTINUE UNTIL ONE MEASUREMENT EXCEEDS THE P-C LIMITS.

     -- IF SO, STEP #2 SHOULD BE REPEATED.

PRE-CONTROL CHART

PART # AEC- 5490 Compression

SPECIFICATION: Free Length .750 ±.010



Observation #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32		
Date	4/12																																	
Time	8:30	10:00		10:30		11:00					12:00	1:00	2:00	3:00						4:00	5:00	6:00												
Measurement	.7645	.7423	.7432	.7557	.7410	.7572	.7462	.7503	.7540	.7460	.7509	.7460	.7524	.7563	.7480	.7492	.7518	.7540	.7474	.7456	.7502	.7463												
	ADJUST		ADJUST		OUT OF CONTROL					GO TO ONE/HOUR									GO TO ONE/HOUR															

TYPES OF ATTRIBUTES CONTROL CHARTS

- p CHART: PROPORTION OF UNITS NONCONFORMING.
  CONSTANT SAMPLE SIZE NOT REQUIRED.

- np CHART: NUMBER OF UNITS NONCONFORMING.
  CONSTANT SAMPLE SIZE REQUIRED.

- c CHART: NUMBER OF NONCONFORMITIES.
  CONSTANT SAMPLE SIZE REQUIRED.

- u CHART: NUMBER OF NONCONFORMITIES PER UNIT.
  CONSTANT SAMPLE SIZE NOT REQUIRED.

p CHART - ATTRIBUTES TYPE CONTROL CHART FOR PROPORTION OF UNITS NONCONFORMING (DEFECTIVES) FROM SAMPLES (SUBGROUPS) THAT ARE NOT REQUIRED TO BE OF THE SAME (CONSTANT) SIZE.

SUMMARY GUIDELINE (NOT A PROCEDURE):

- DETERMINE FREQUENCY AND ESTIMATED SIZE OF SAMPLES. SAMPLE SIZES (OBSERVATIONS) SHOULD BE LARGE ENOUGH SO THAT THERE IS A GOOD POSSIBILITY OF AT LEAST 2 TO 5 DEFECTIVE UNITS PER SAMPLE.

- COLLECT SAMPLE DATA UNTIL OBTAIN 20 TO 25 SAMPLES. SIZE OF SAMPLES SHOULD NOT VARY BY MORE THAN +/- 25%. OTHERWISE, ADDITIONAL CALCULATIONS MAY BE REQUIRED.

- RECORD EACH SAMPLE'S NUMBER OF OBSERVED UNITS NONCONFORMING AND THE SAMPLE SIZE. SELECT SCALES FOR CHART.

- CALCULATE EACH SAMPLE'S PROPORTION OF UNITS NONCONFORMING (p) BY DIVIDING THE NUMBER OF OBSERVED UNITS NONCONFORMING IN THE SAMPLE BY THE PARTICULAR SAMPLE SIZE:

$$P = \frac{np}{n}$$

- PLOT THE INDIVIDUAL SAMPLES UNTIL OBTAIN 20 TO 25 POINTS.

- CALCULATE THE PROCESS AVERAGE PROPORTION NONCONFORMING ($\bar{p}$) BY DIVIDING THE TOTAL NUMBER OF NONCONFORMING UNITS OBSERVED IN ALL OF THE SAMPLES BY THE TOTAL NUMBER OF OBSERVATIONS FOR ALL OF THE SAMPLES.

- CALCULATE THE UPPER AND LOWER CONTROL LIMITS:

$$UCL_p = \bar{p} + 3\sqrt{\frac{\bar{p}\ (1-\bar{p})}{\bar{n}}}$$

$$LCL_p = \bar{p} - 3\sqrt{\frac{\bar{p}\ (1-\bar{p})}{\bar{n}}}$$

$\bar{n}$ = AVERAGE SAMPLE SIZE

- DRAW CONTROL LIMIT LINES AND INTERPRET FOR CONTROL AND CAPABILITY.

ATTRIBUTE DATA CONTROL CHART

Part # AEC-5490 Compression

Operation Testing

Average = 18.81 %

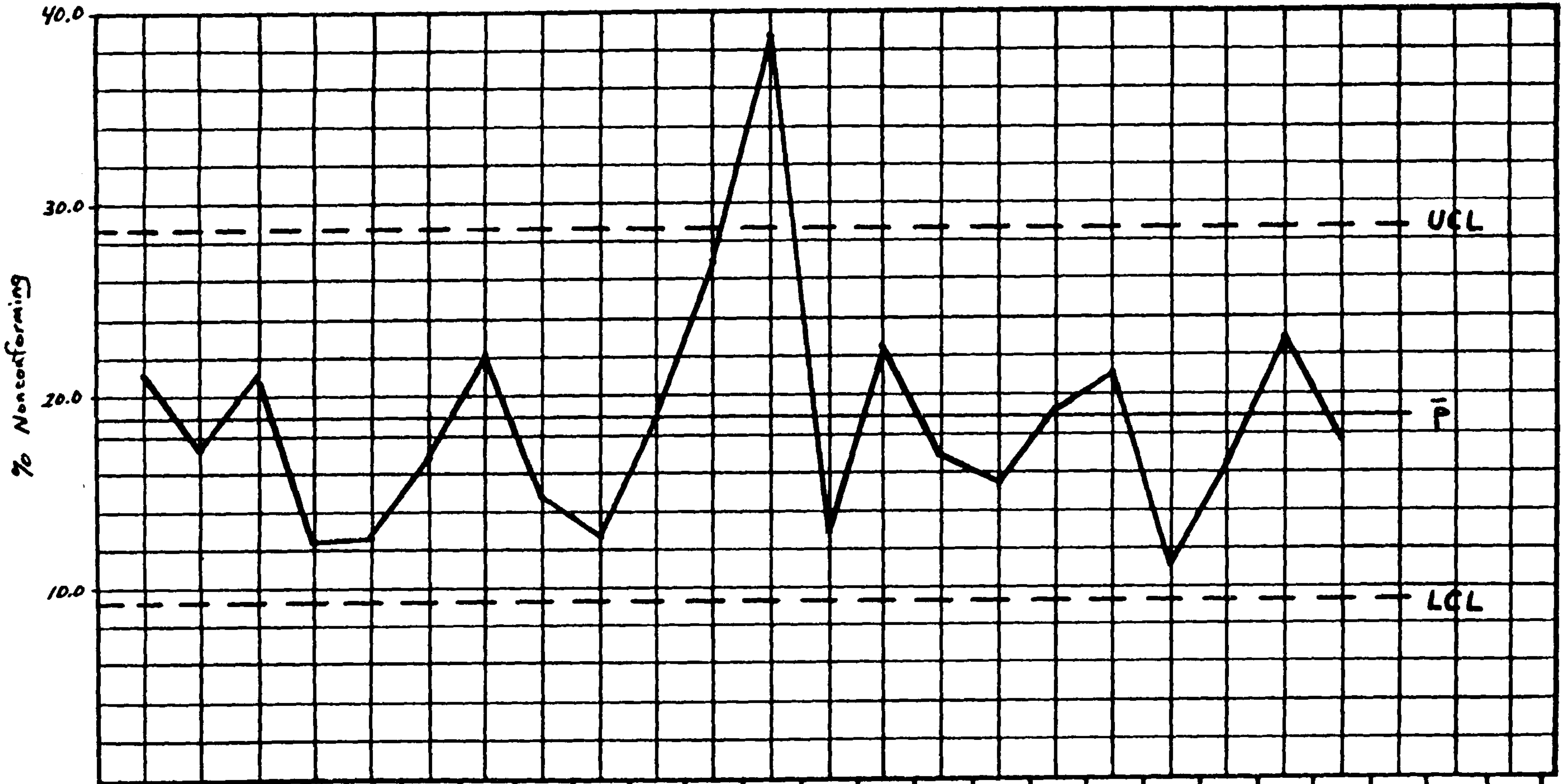
UCL = 28.43%

LCL = 9.19%

Ave. Sample Size = 148.4

Frequency = Once per hour

p ☒ np ☐ c ☐ u ☐



Sample (n)	160	160	150	155	135	135	145	140	150	165	140	145	160	160	140	145	150	160	150	140	135	145
Observed (np,c)	34	28	32	19	17	23	32	21	19	31	38	56	21	36	24	23	29	34	17	23	31	26
Proportion (p,u)	21.2	17.5	21.3	12.3	12.6	17.0	22.1	15.0	12.7	18.8	27.1	38.6	13.1	22.5	17.1	15.7	19.3	21.2	11.3	16.4	23.0	17.9
Date/No.	4/15 8 AM	9	10	11	12	1 PM	2	3	4	5	6	7	8	9	10	11	12	4/16 1 AM	2	3	4	5
Notes												CHANGED COIL										

np CHART - ATTRIBUTES TYPE CONTROL CHART FOR NUMBER OF UNITS NONCONFORMING FROM SAMPLES (SUBGROUPS) OF THE SAME (CONSTANT) SIZE.

SUMMARY GUIDELINE (NOT A PROCEDURE):

- DETERMINE FREQUENCY AND SIZE OF SAMPLES. SAMPLE SIZE (OBSERVATIONS) SHOULD BE LARGE ENOUGH SO THAT THERE IS A GOOD POSSIBILITY OF AT LEAST 2 TO 5 DEFECTIVE UNITS PER SAMPLE.

- COLLECT SAMPLE DATA UNTIL OBTAIN 20 TO 25 SAMPLES. SIZES OF SAMPLES SHOULD BE OF THE SAME (CONSTANT) SIZE. SELECT SCALES FOR CHART.

- RECORD EACH SAMPLE'S NUMBER OF UNITS NONCONFORMING (np).

- PLOT THE INDIVIDUAL SAMPLES UNTIL OBTAIN 20 TO 25 points.

- CALCULATE THE PROCESS AVERAGE NUMBER NONCONFORMING ($n\bar{p}$) BY DIVIDING THE TOTAL NUMBER OF NONCONFORMING OBSERVATIONS FOR ALL SAMPLES BY NUMBER OF SAMPLES (SUBGROUPS).

- CALCULATE THE UPPER AND LOWER CONTROL LIMITS:

$$UCL_{np} = n\bar{p} + 3\sqrt{n\bar{p}\,(1 - \frac{n\bar{p}}{n})}$$

$$LCL_{np} = n\bar{p} - 3\sqrt{n\bar{p}\,(1 - \frac{n\bar{p}}{n})}$$

- DRAW CONTROL LIMITS AND INTERPRET FOR CONTROL AND CAPABILITY.

ATTRIBUTE DATA CONTROL CHART

Part # AEC-5490 Compression

Operation Testing

Average = 17.6

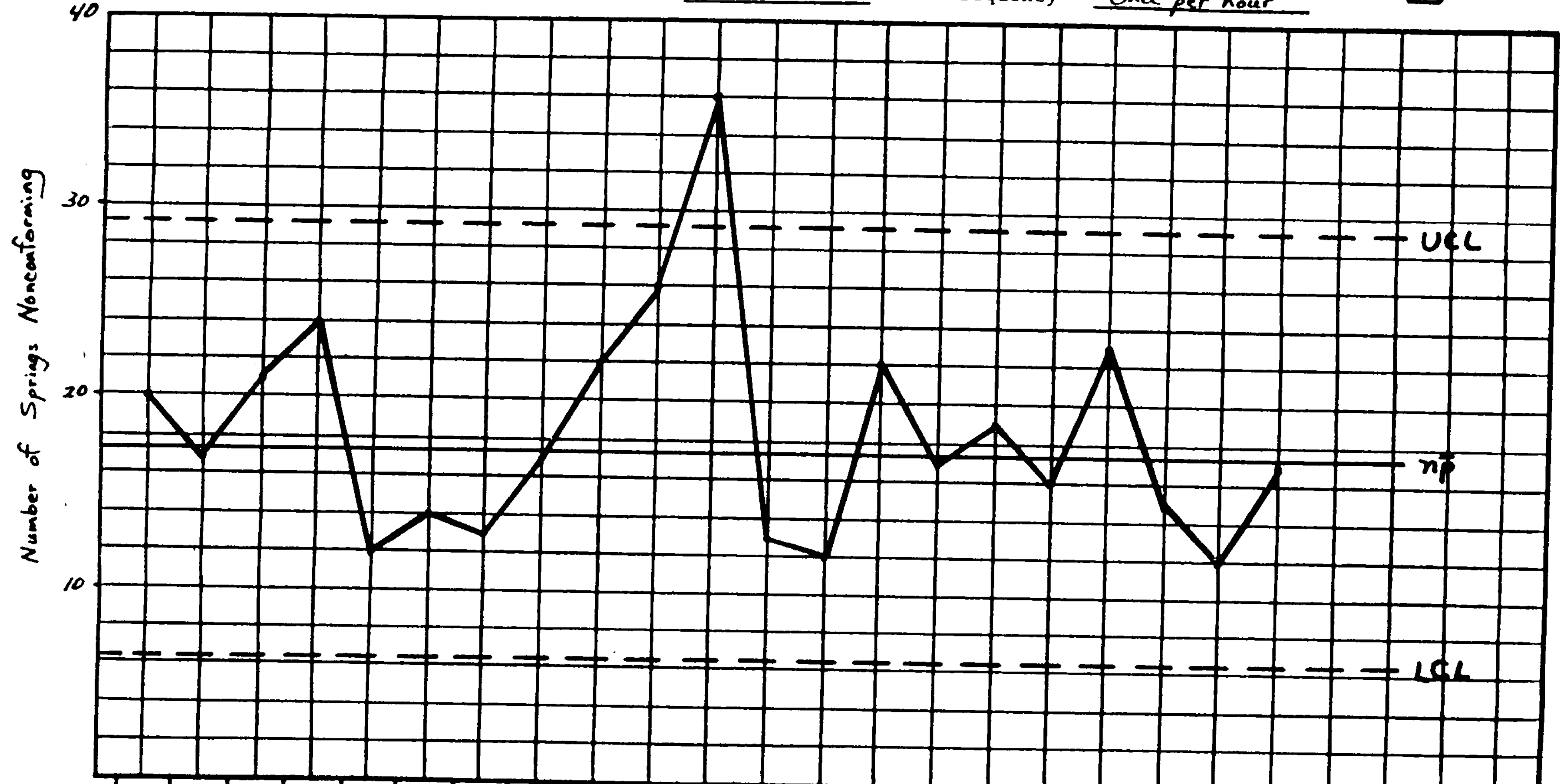
UCL = 29.02

LCL = 6.18

Ave. Sample Size = 100

Frequency = Once per hour

p ☐ np ☒ c ☐ u ☐



Sample	100 →																				
Observed	20	17	21	24	12	14	13	17	22	26	36	13	12	22	17	19	16	23	15	12	17
Proportion																					
Date/No.	7/15 8AM	9	10	11	12	1PM	2	3	4	5	6	7	8	9	10	11	12	7/16 1AM	2	3	4
Notes												CHANGED COIL 7:40									

n

np

p,u

C CHART - ATTRIBUTES TYPE CONTROL CHART FOR NUMBER OF NONCONFORMITIES FROM SAMPLES (SUBGROUPS) OF THE SAME (CONSTANT) SIZE.

SUMMARY GUIDELINE (NOT A PROCEDURE):

- DETERMINE FREQUENCY AND SIZE OF SAMPLES (MAY BE ONE UNIT OF PRODUCT SUCH AS A COIL OF WIRE). SAMPLE SIZE SHOULD BE LARGE ENOUGH SO THAT THERE IS A GOOD POSSIBILITY OF NONCONFORMING OCCURRENCES IN EACH SAMPLE.

- COLLECT DATA, SELECT SCALES, RECORD, AND PLOT NUMBER OF NONCONFORMITIES (C) FOR EACH SAMPLE.

- PLOT THE INDIVIDUAL SAMPLES UNTIL OBTAIN 20 TO 25 POINTS.

- CALCULATE THE PROCESS AVERAGE NUMBER OF NONCONFORMITIES ($\bar{c}$) BY DIVIDING THE TOTAL NUMBER OF NONCONFORMITIES OBSERVED FOR ALL SAMPLES BY THE NUMBER OF SAMPLES (SUBGROUPS).

- CALCULATE THE UPPER AND LOWER CONTROL LIMITS:

$$UCL_C = \bar{c} + 3\sqrt{\bar{c}}$$

$$LCL_C = \bar{c} - 3\sqrt{\bar{c}}$$

- DRAW CONTROL LIMITS AND INTERPRET FOR CONTROL AND CAPABILITY.

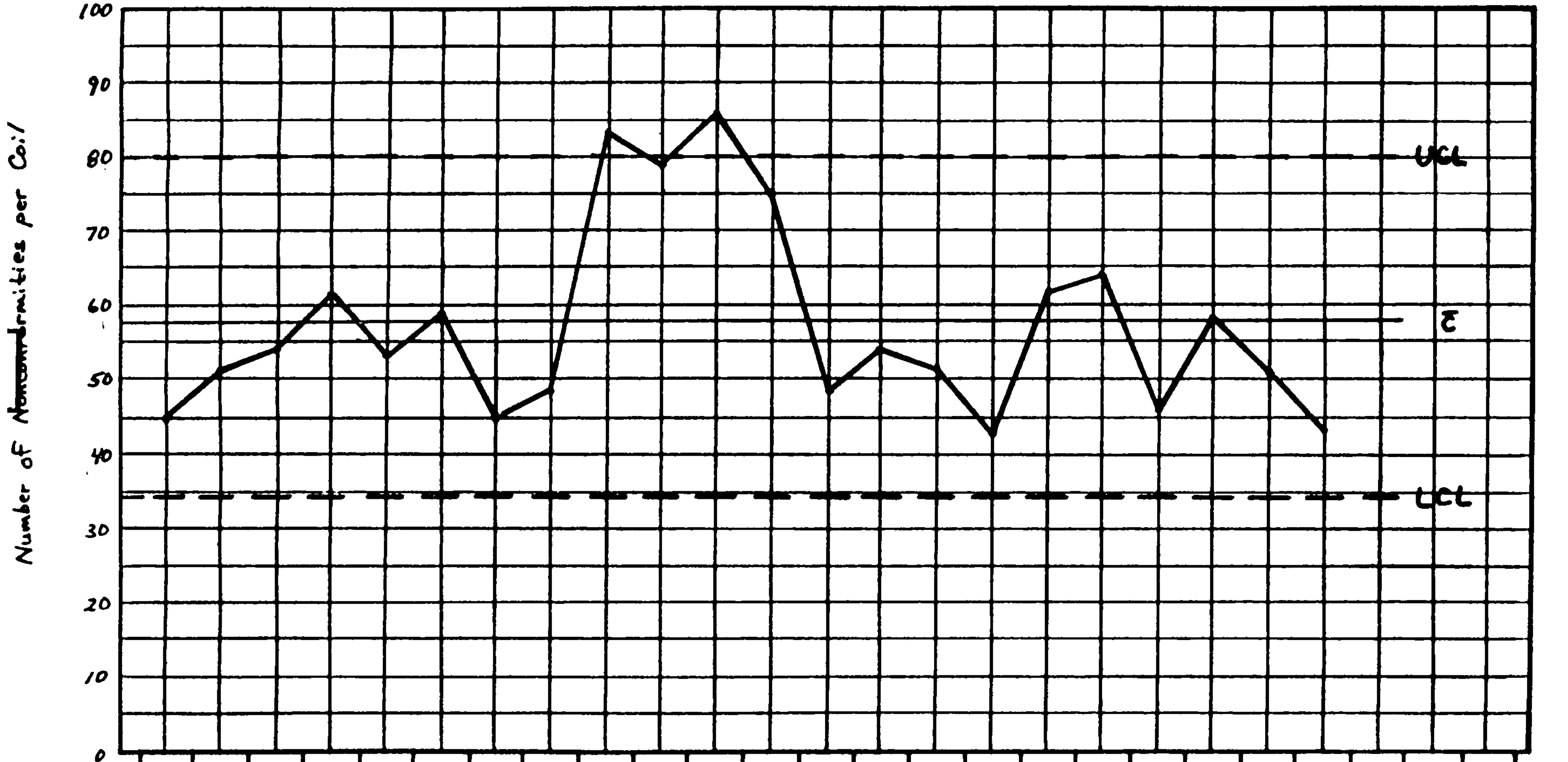
ATTRIBUTE DATA CONTROL CHART

p ☐ np ☐ c ☒ u ☐

Part # AEC-5490 Compression
Operation Coiling #23 (Lyons Gage)
Free Length .750 ± .010

Average = 57.3
UCL = 80.0
LCL = 34.6

Ave. Sample Size = Whole coil
Frequency = Each coil



Sample	1 →																										n
Observed	45	51	54	62	53	59	45	48	83	79	86	75	48	54	52	43	62	64	46	58	51	43					np,c
Proportion																											p,u
Date/Coil # No.	4/15 1	2	3	4	4/16 5	6	7	8	4/17 9	10	11	12	4/18 13	14	15	16	4/19 17	18	19	20	4/20 21	22					
Notes									Different heat #				Different heat #														

u CHART - ATTRIBUTES TYPE CONTROL CHART FOR NUMBER OF NONCONFORMITIES (DEFECTS) PER UNIT FROM SAMPLES (SUBGROUPS) THAT ARE NOT REQUIRED TO BE OF THE SAME (CONSTANT) SIZE.

SUMMARY GUIDELINE (NOT A PROCEDURE):

- DETERMINE FREQUENCY AND ESTIMATED SIZE OF SAMPLES. SAMPLE SIZES (OBSERVATIONS) SHOULD BE LARGE ENOUGH SO THAT THERE IS A GOOD POSSIBILITY OF NONCONFORMING OCCURRENCES IN EACH SAMPLE.

- COLLECT DATA UNTIL OBTAIN 20 TO 25 SAMPLES (HOWEVER, MAY BE LESS). SIZES OF SAMPLES SHOULD NOT VARY BY MORE THAN +/- 25%. OTHERWISE, ADDITIONAL CALCULATIONS MAY BE REQUIRED.

- RECORD EACH SAMPLE'S NUMBER OF NONCONFORMITIES OBSERVED AND THE SAMPLE SIZE. (IT SHOULD BE NOTED THAT THE NUMBER OF NONCONFORMITIES FOR A PARTICULAR SAMPLE MAY EXCEED THAT SAMPLE'S SIZE.) SELECT SCALES FOR CHART.

- CALCULATE EACH SAMPLE'S NONCONFORMITIES (DEFECTS) PER UNIT (u) BY DIVIDING THE NUMBER OF NONCONFORMITIES OBSERVED IN THE SAMPLE BY THE PARTICULAR SAMPLE SIZE OR:

$$u = \frac{c}{n}$$

- PLOT THE INDIVIDUAL SAMPLES.

- CALCULATE THE PROCESS AVERAGE NONCONFORMITIES PER UNIT ($\bar{u}$) BY DIVIDING THE TOTAL NUMBER OF NONCONFORMITIES PER UNIT (u) IN ALL OF THE SAMPLES BY THE TOTAL NUMBER OF SAMPLES (SUBGROUPS).

- CALCULATE THE UPPER AND LOWER CONTROL LIMITS:

$$UCL_u = \bar{u} + 3\sqrt{\frac{\bar{u}}{\bar{n}}}$$

$$LCL_u = \bar{u} - 3\sqrt{\frac{\bar{u}}{\bar{n}}}$$

$\bar{n}$ = AVERAGE SAMPLE SIZE

- DRAW CONTROL LIMIT LINES AND INTERPRET FOR CONTROL AND CAPABILITY.

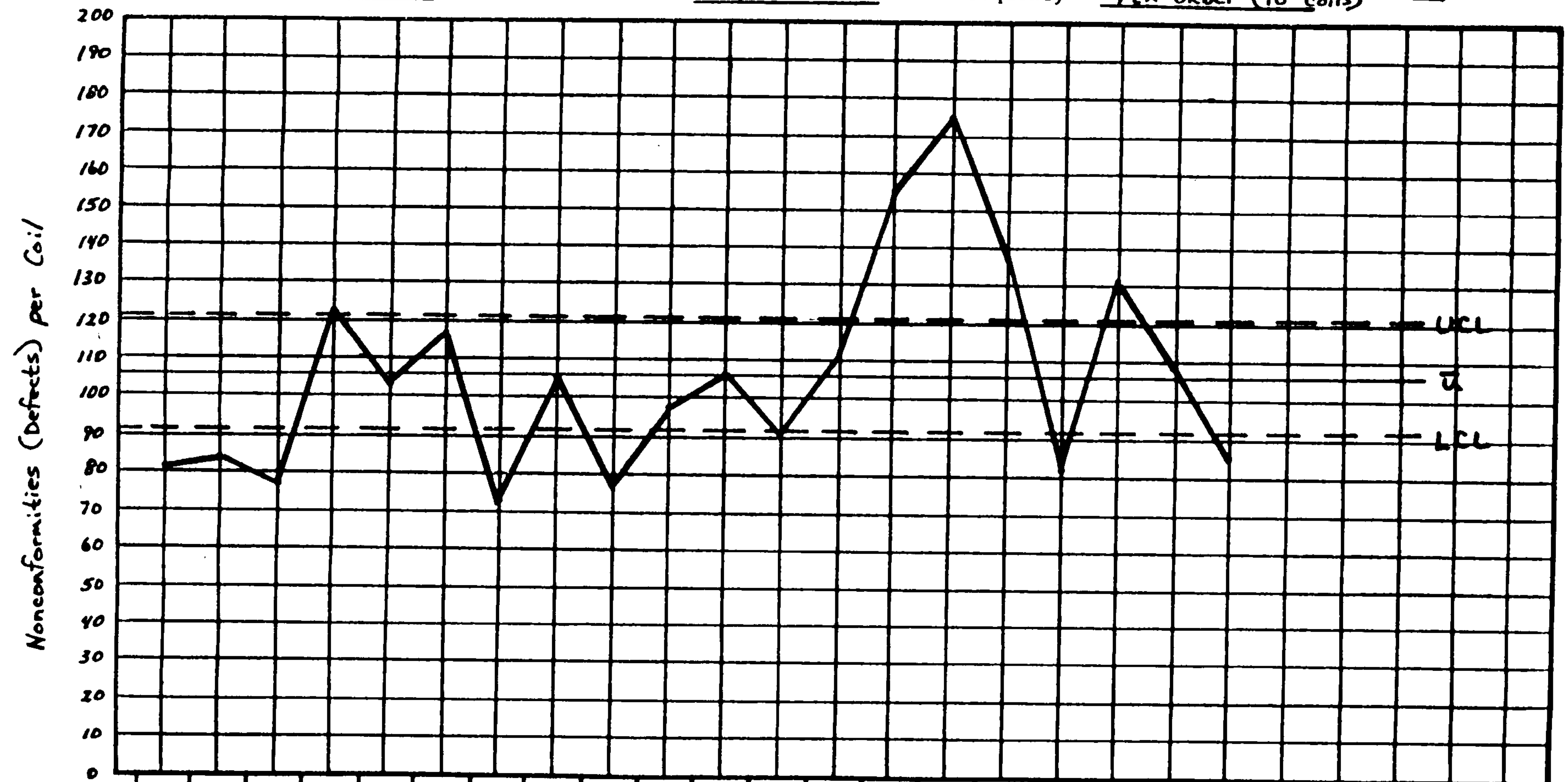
ATTRIBUTE DATA CONTROL CHART

Part # AEC-5490 Compression
Operation Testing
All characteristics

Average = 106.22
UCL = 120.9
LCL = 91.5

Ave. Sample Size = 4.4 coils
Frequency = PER ORDER (10# coils)

p ☐
np ☐
c ☐
u ☒



Sample	4	5	4	4	5	4	4	4	5	4	4	5	4	4	4	5	5	4	4	5							n
Observed	322	421	308	492	520	471	291	424	389	390	425	453	443	621	703	689	408	522	435	433							np,c
Proportion	80.5	84.2	77.0	123.0	104.0	117.8	72.8	106.0	77.8	97.5	106.2	90.6	110.8	155.2	175.8	137.8	81.6	130.5	108.8	86.6							p (u)
Date/No.	4/15	4/16	4/20	4/21	4/22	4/30	5/1	5/2	5/3	5/6	5/7	5/8	5/10	5/14	5/15	5/16	5/20	5/23	5/24	5/25							
Notes				Changed heat #			Changed heat #					Alternate supplier															

PRELIMINARY CONSIDERATIONS BEFORE PERFORMING A CAPABILITY STUDY TO EVALUATE WHETHER A PROCESS IS IN A STATE OF STATISTICAL CONTROL:

° SELECT CHARACTERISTIC(S) TO STUDY TO ESTIMATE INHERENT PROCESS VARIABILITY. DETERMINE WHICH MACHINE GENERATES CHARACTERISTIC OR A REPRESENTATIVE MACHINE MAY BE SELECTED. (HOWEVER, BE CAREFUL!)

° DETERMINE AND DEFINE THE PROCESS PARAMETERS THAT ARE AGREED TO AND ACCEPTABLE FOR MANUFACTURING. SHOULD ATTEMPT TO FOLLOW MANUFACTURING PROCESSES SO THAT TYPICAL PROCESS VARIATION MAY BE EVALUATED WITH REALISTIC OPERATING CONDITIONS.

° DETERMINE WHEN STUDY CAN BE PERFORMED WITH MINIMAL DISRUPTIONS TO DATA COLLECTION AND NORMAL OPERATIONS.

° DETERMINE PRACTICAL SAMPLE SIZE THAT IS LARGE ENOUGH TO OBTAIN NECESSARY DATA. PROVIDE EFFICIENT METHOD TO ACCUMULATE COLLECTED DATA IN THE PROPER SEQUENCE. SUBGROUPING SHOULD ALLOW FOR SELECTING REPRESENTATIVE SAMPLES THROUGHOUT THE POPULATION. PERHAPS, MORE THAN ONE PRODUCTION RUN SHOULD BE INCLUDED.

° PROVIDE ADEQUATE MEASUREMENT DEVICES AND DETERMINE MEASUREMENT PROCEDURE TO ACCURATELY EVALUATE THE CHARACTERISTIC(S). ALL MEASUREMENT DEVICES MUST BE CALIBRATED.

° SELECT A REPRESENTATIVE AND QUALIFIED OPERATOR. IF NECESSARY, TRAIN OPERATOR FOR STUDY. PROVIDE NECESSARY FORMS FOR DATA COLLECTION.

AEC-5490 Compression

Process Capability

Free Length .750 ±.010 Machine #23 Coiling [signature] 4/15

1	.7521	.7541	.7478	.7540	.7477			
2	.7514	.7478	.7522	.7469	.7498			
3	.7478	.7529	.7531	.7477	.7487			
4	.7521	.7518	.7507	.7516	.7498			
5	.7591	.7516	.7521	.7515	.7517			
6	.7483	.7504	.7522	.7489	.7476			
7	.7528	.7551	.7538	.7528	.7499			
8	.7506	.7532	.7501	.7516	.7509			
9	.7533	.7531	.7542	.7507	.7571			
10	.7469	.7507	.7494	.7503	.7499			
11	.7532	.7561	.7541	.7499	.7532			
12	.7540	.7537	.7529	.7488	.7536			
13	.7523	.7513	.7507	.7523	.7518			
14	.7509	.7507	.7550	.7520	.7523			
15	.7498	.7503	.7505	.7512	.7521			
16	.7467	.7514	.7507	.7489	.7499			
17	.7487	.7492	.7540	.7543	.7532			
18	.7552	.7560	.7513	.7531	.7532			
19	.7512	.7516	.7504	.7528	.7499			
20	.7516	.7523	.7550	.7515	.7513			

PROCESS CAPABILITY: HISTOGRAM - DEVELOP HISTOGRAM TO DETERMINE VARIABILITY OF A PROCESS. THEN, CAN BE COMPARED TO SPECIFICATION LIMITS TO EVALUATE ACCEPTABILITY. IT SHOULD BE NOTED THAT CERTAIN CUSTOMERS MAY REQUIRE SHORT AND LONG-TERM STUDIES AND SHOULD BE CONTACTED FOR SPECIFIC REQUIREMENTS.

SUMMARY GUIDELINE (NOT A PROCEDURE):

- SELECT CHARACTERISTIC TO STUDY. COLLECT INDIVIDUAL MEASUREMENTS (EITHER TAKEN RANDOMLY OR TAKEN CONSECUTIVELY, 25 TO 300 READINGS). DO NOT ADJUST.

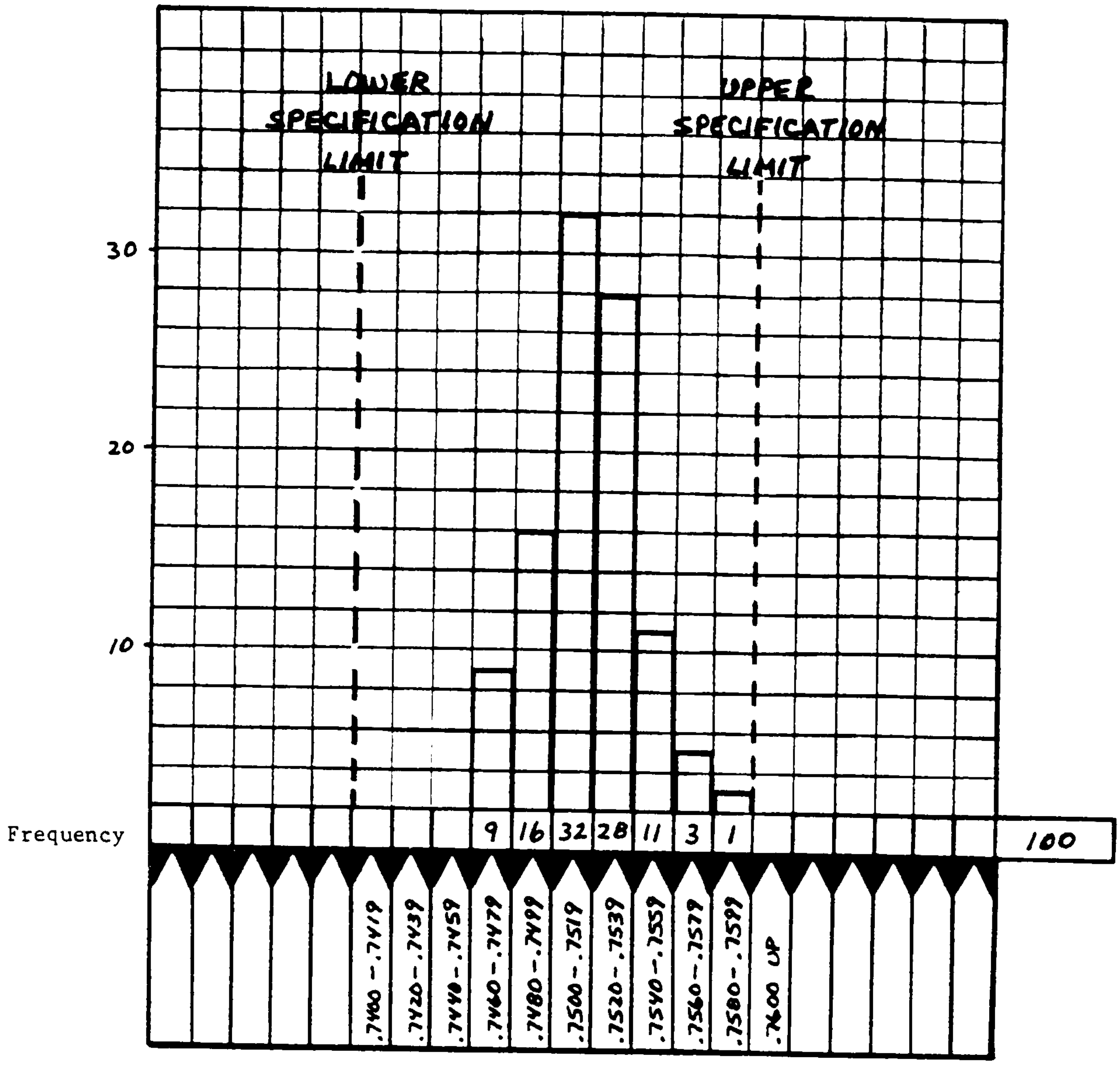
- CALCULATE +/- 3 SIGMA LIMITS (STANDARD DEVIATIONS) FOR THE MEASUREMENTS.

- DRAW HISTOGRAM OF THE INDIVIDUAL MEASUREMENTS TO REVIEW DISTRIBUTION AND CENTERING. INDICATE THE SPECIFICATION LIMITS.

- GENERALLY, THE CAPABILITY RATIO (6 STANDARD DEVIATIONS DIVIDED BY THE TOTAL TOLERANCE) SHOULD NOT EXCEED 75% FOR CURRENT PROCESS OR 67% FOR NEW PROCESSES. ALSO, OTHER INDEXES MAY BE UTILIZED (FOR EXAMPLE, C_pK, ETC.)

- IT SHOULD BE NOTED THAT THE HISTOGRAM METHOD DOES NOT EVALUATE WHETHER THE PROCESS IS IN A STATE OF CONTROL. TO DETERMINE CONTROL, THE CONTROL CHART METHOD SHOULD BE UTILIZED.

HISTOGRAM CAPABILITY CHART



Date: 4/16

Part #: AEC-5490 Compression

Operation: Coiling

Machine #: 23

Characteristic: Free Length

Dimension/Tolerance: .750 ±.010

Capability Ratio = $\frac{6 \times .00230}{.020}$ = 69.0%

Other calculations (CP, CPK, Z, etc.):

Number of Observations: 100

Average (Mean) = .75156

sigma = .00230

+3 sigma = .75846

-3 sigma = .74466

Signed: [signature]

4/18/85

PROCESS CAPABILITY: INDIVIDUAL MEASUREMENTS - A METHOD OF PLOTTING IN TIME SEQUENCE CONSECUTIVE MEASUREMENTS. THE VALUES ARE THEN REVIEWED IN RELATION TO THE TOLERANCE LIMITS. IT SHOULD BE NOTED THAT THIS TYPE OF ANALYSIS DOES NOT REQUIRE CALCULATIONS NOR DOES IT DETERMINE THE PROCESS DISTRIBUTION OR STATE OF CONTROL.

SUMMARY GUIDELINE (NOT A PROCEDURE):

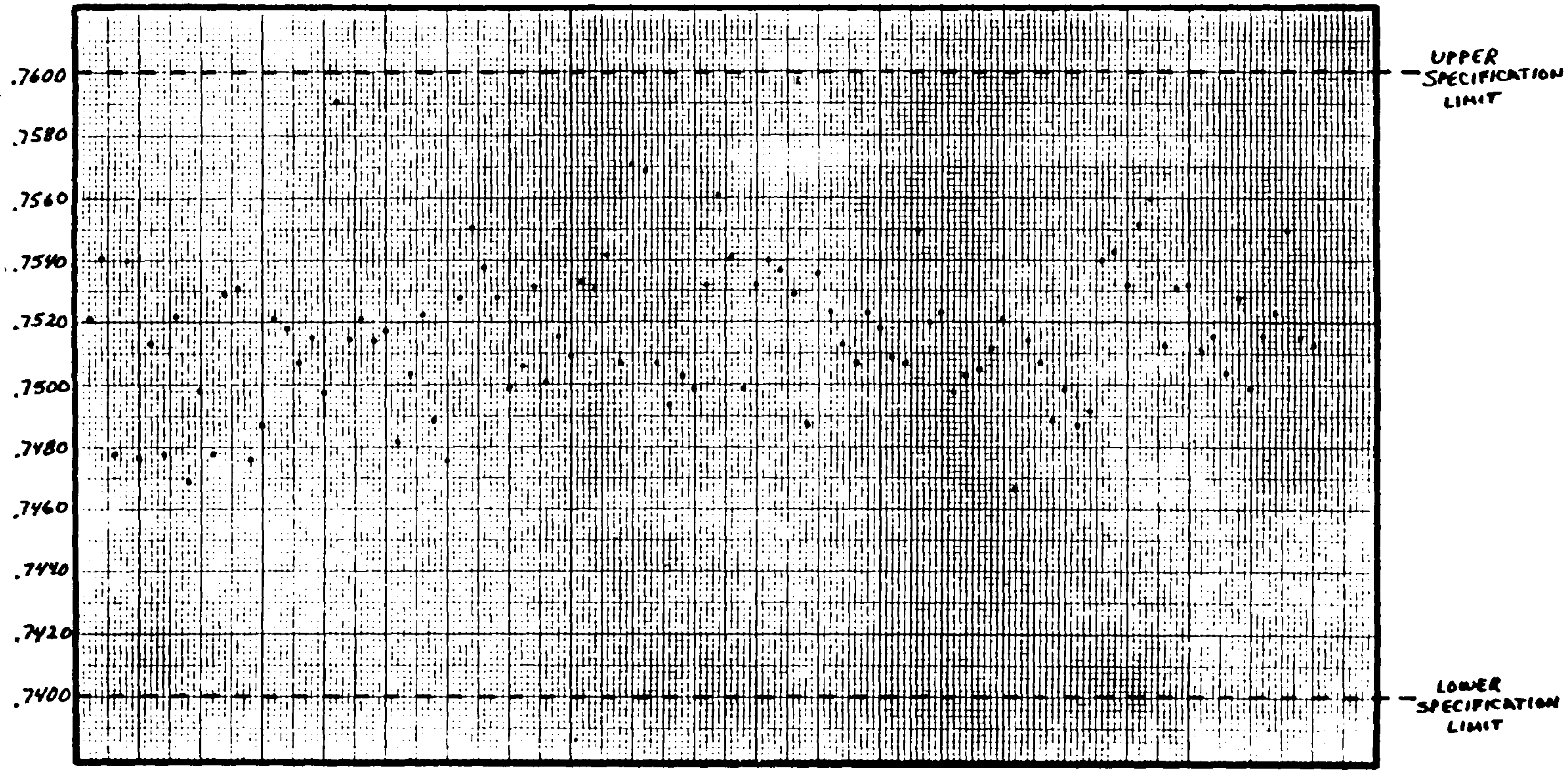
- SELECT CHARACTERISTIC TO STUDY AND COLLECT DATA. GENERALLY, CONSECUTIVE MEASUREMENTS (50 TO 500) ARE TAKEN IN OPERATING SEQUENCE.

- PLOT IN SEQUENCE EACH MEASUREMENT. PLOT (DRAW DASHED LINES) FOR THE UPPER AND LOWER SPECIFICATION LIMITS.

- REVIEW PLOTTED POINTS IN RELATION TO THE SPECIFICATION LIMITS. DATA MAY BE REVIEWED POINTS NOT WITHIN SPECIFICATION AND VARIATION OVER TIME.

INDIVIDUAL PLOT - CAPABILITY

Part # AEC-5490 Compression



Operation #: Coiling

Machine #: 23

Characteristic: Free Length

Dimension/Tolerance: .750 ± .010

Signed: [signature] 4/16/85

PROCESS CAPABILITY: $\bar{X}$ AND R CHART - UTILIZE CONTROL CHART METHOD TO DETERMINE CAPABILITY AND, AS REQUIRED, COMPARE TO SPECIFICATION LIMITS. IT SHOULD BE NOTED THAT CERTAIN CUSTOMERS MAY REQUIRE **SHORT-TERM** (PERFORMED UNDER CONTROLLED CONDITIONS) AND/OR **LONG-TERM** (PERFORMED OVER A LONGER TIME PERIOD UNDER NORMAL OPERATING CONDITIONS). THE CUSTOMERS SHOULD BE CONTACTED FOR SPECIFIC SAMPLING AND CAPABILITY REQUIREMENTS.

SUMMARY GUIDELINE FOR TYPICAL STUDY (NOT A PROCEDURE):

- SELECT CHARACTERISTIC TO STUDY AND COLLECT DATA TO REPRESENT TYPICAL VARIATION. FOR EXAMPLE, MAY SELECT 5 CONSECUTIVE MEASUREMENTS AT REGULAR INTERVALS FOR AT LEAST 10 SUBGROUPS (SAMPLES). OR, MAY TAKE A LARGE SAMPLE OF CONSECUTIVE MEASUREMENTS (100 TO 300) AT ONE TIME. THE LARGE SAMPLE IS THEN DIVIDED INTO SEVERAL (AT LEAST 9 TO 12) EQUAL SIZE SUBGROUPS OF 4 TO 6 CONSECUTIVE MEASUREMENTS EACH.
- CALCULATE THE AVERAGE ($\bar{X}$) AND RANGE (R) FOR EACH SUBGROUP. THEN, CALCULATE THE AVERAGE OF THE AVERAGE ($\bar{\bar{X}}$) AND AVERAGE RANGE ($\bar{R}$) FOR EACH. CALCULATE AND PLOT THE INDIVIDUAL SUBGROUPS AND CONTROL LIMITS:

$$UCL_{\bar{X}} = \bar{\bar{X}} + A_2\bar{R} \qquad UCL_R = D_4\bar{R}$$
$$LCL_{\bar{X}} = \bar{\bar{X}} - A_2\bar{R} \qquad LCL_R = D_3\bar{R}$$

- CHECK THAT ALL PLOTTED POINTS ($\bar{X}$ AND R) ARE WITHIN THE CONTROL LIMITS. IF ONE OR MORE POINTS EXCEED LIMITS, INVESTIGATE CAUSE. IF NECESSARY, REPEAT DATA COLLECTION OR CALCULATE NEW LIMITS WITH ANY OUT OF CONTROL POINTS DELETED (AS JUSTIFIED BY INVESTIGATION OF CAUSE).
- FOR PROCESS IN CONTROL, THE STANDARD DEVIATION MAY BE CALCULATED (REFER TO APPENDIX FOR CONSTANTS):

$$\hat{\sigma} = \frac{\bar{R}}{d_2}$$

- GENERALLY, DETERMINE PROCESS CAPABILITY AS 6 STANDARD DEVIATIONS. REVIEW SPREAD AS PERCENTAGE OF SPECIFICATION TOLERANCE (CAPABILITY RATIO = 6S DIVIDED BY TOTAL TOLERANCE). ALSO, CHECK AVERAGE (MEAN) OF THE INDIVIDUAL MEASUREMENTS AND COMPARE TO CENTER OF SPECIFICATION (FOR EXAMPLE, CAN USE C_pK INDEX). PROCESS SHOULD BE CENTERED WITH THE CAPABILITY RATIO NOT EXCEEDING THE TOTAL TOLERANCE (USUALLY 70% - 75% FOR SHORT-TERM).
- IF PROCESS IS NOT CAPABLE, REVIEW AND MAKE NECESSARY ADJUSTMENTS. THEN, REVIEW DATA AND DETERMINE CONTROL.
- ONCE ACCEPTABLE CAPABILITY DETERMINED, CONTROL CHARTING ACTIVITY MAY BE CONTINUED FOR A LONGER PERIOD OF TIME. FOR EXAMPLE, THE CHART SHOULD INCLUDE A MINIMUM OF 20 TO 25 SUBGROUPS (SAMPLES) WITH A MINIMUM OF 5 CONSECUTIVE MEASUREMENTS. CAPABILITY (GENERALLY 100% OR LESS OF TOLERANCE) CAN THEN BE CALCULATED OVER A LONGER OPERATING TIME PERIOD.

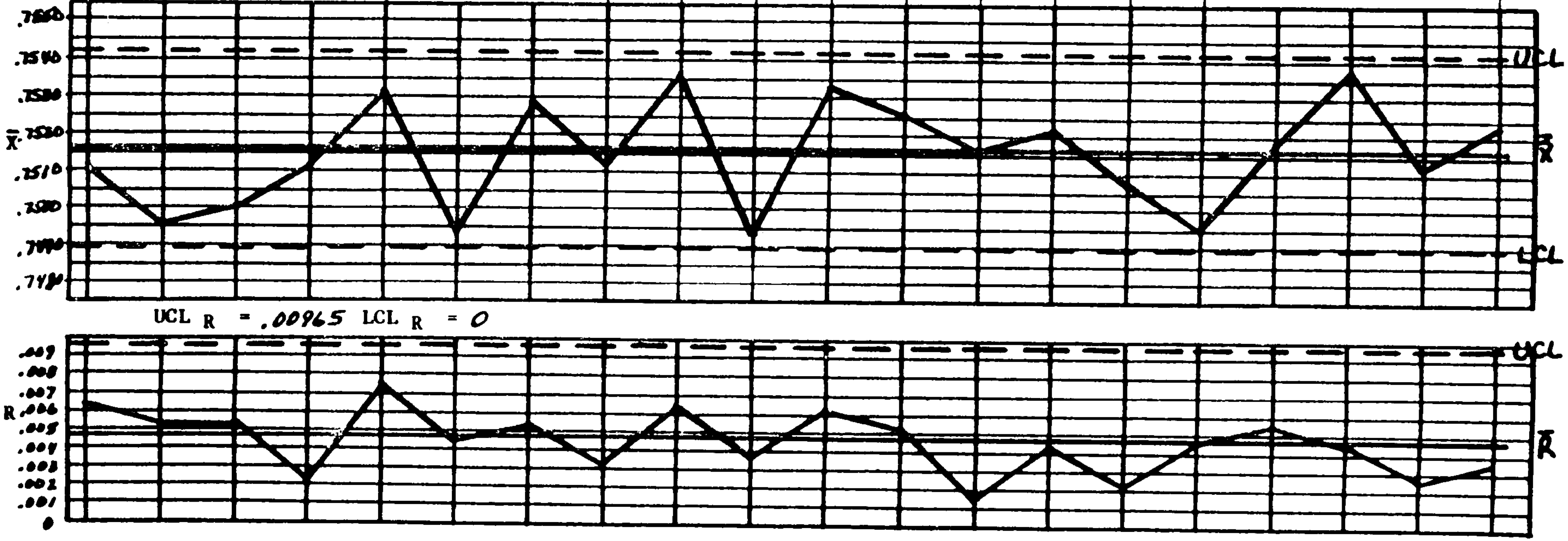
CAPABILITY STUDY - CONTROL CHART

Part # AEC-5490 Compression

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	.7521	.7514	.7478	.7521	.7591	.7483	.7528	.7506	.7533	.7469	.7532	.7540	.7523	.7509	.7498	.7467	.7487	.7552	.7512	.7516
	.7541	.7478	.7529	.7518	.7516	.7504	.7551	.7532	.7531	.7507	.7561	.7537	.7513	.7507	.7503	.7514	.7492	.7560	.7516	.7523
	.7478	.7522	.7531	.7507	.7521	.7522	.7538	.7501	.7542	.7494	.7541	.7529	.7507	.7550	.7505	.7507	.7540	.7513	.7504	.7550
	.7540	.7469	.7477	.7516	.7515	.7489	.7528	.7516	.7507	.7503	.7499	.7488	.7523	.7520	.7512	.7489	.7543	.7531	.7528	.7515
	.7477	.7498	.7487	.7498	.7517	.7476	.7499	.7509	.7571	.7499	.7532	.7536	.7518	.7523	.7521	.7499	.7532	.7532	.7499	.7513
Tot.	3.7557	3.7481	3.7502	3.7560	3.7660	3.7474	3.7644	3.7564	3.7684	3.7472	3.7665	3.7630	3.7584	3.7609	3.7539	3.7476	3.7594	3.7688	3.7559	3.7617
X̄	.75114	.74962	.75004	.75120	.75320	.74948	.75288	.75128	.75368	.74944	.75330	.75260	.75168	.75218	.75078	.74952	.75188	.75376	.75118	.75234
R	.0064	.0053	.0054	.0023	.0076	.0046	.0052	.0031	.0064	.0038	.0062	.0052	.0016	.0043	.0023	.0047	.0056	.0047	.0029	.0037

UCL $\bar{X}$ = .754193   LCL $\bar{X}$ = .748925

$\bar{\bar{X}}$ = .751559
$\bar{R}$ = .004565



Operation: Ceiling
Machine: 23
Characteristic: Free Length
Dimension/Tolerance:
.750 ±.010

$\hat{\sigma} = \frac{\bar{R}}{d_2} = \frac{.004565}{2.326} = .001963$

Capability ratio = $\frac{.011778}{.020}$ = 58.9 %

Signed/Date: [signature] 4/17

MACHINE CAPABILITY - METHOD TO EVALUATE MACHINE ABILITY TO MEET TOLERANCES

° USE TO RATE AND/OR SELECT MACHINES FOR SPECIFIC REQUIREMENTS.

° USE TO QUALIFY MACHINES FOR USE IN PRODUCTION.

° USE TO EVALUATE MANUFACTURERS' CLAIMS ABOUT MACHINE PERFORMANCE.

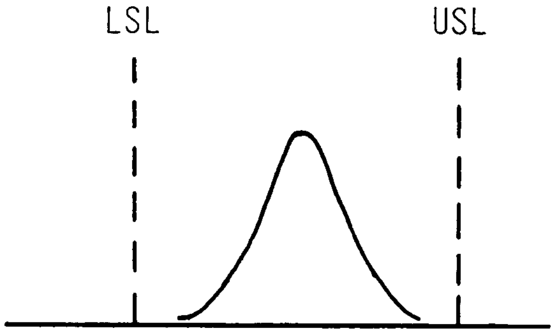
CAN USE SAME METHODS AS FOR CALCULATING PROCESS CAPABILITY. HOWEVER, A MACHINE CAPABILITY STUDY IS GENERALLY A SHORT-TERM EVALUATION THAT IS PERFORMED BY EVALUATING CONSECUTIVE PRODUCTION UNITS DURING ONE TIME PERIOD.

SOME CAPABILITY TERMS

THIS IS AN OVERVIEW OF CONCEPTS AND TERMS. PLEASE CONTACT YOUR CUSTOMER(S) FOR SPECIFIC REQUIREMENTS AND METHODS OF CALCULATION.

- CR IS THE RATIO OF THE 6 SIGMA (STANDARD DEVIATION) LIMITS DIVIDED BY THE TOTAL TOLERANCE:

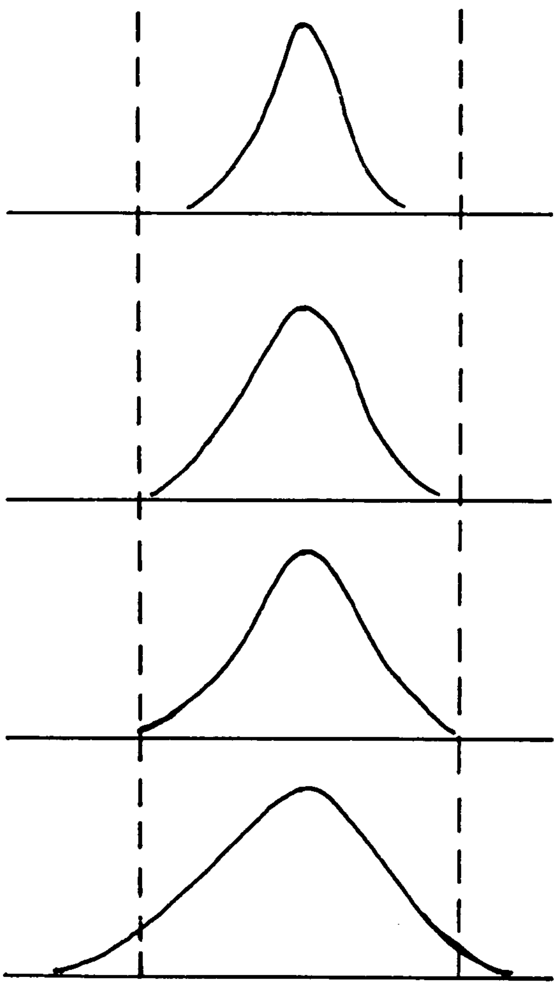
$$CR = \frac{6\hat{\sigma}}{\text{TOTAL TOLERANCE}}$$



70 TO 75% RATIO IS GENERALLY ACCEPTABLE FOR CURRENT PROCESS CAPABILITY BUT DOES NOT RELATE HOW WELL THE PROCESS MEAN IS CENTERED WITHIN THE SPECIFICATION RANGE.

- C_P IS THE RATIO OF THE TOTAL TOLERANCE TO 6 SIGMA.

$$C_P = \frac{\text{TOTAL TOLERANCE}}{6\hat{\sigma}}$$



WHEN C_P = 2.00 OR MORE, PROCESS IS CONSIDERED TO HAVE EXCELLENT CAPABILITY.

WHEN C_P IS BETWEEN 1.34 AND 1.99, PROCESS IS CAPABLE BUT STILL REQUIRES IMPROVEMENT EFFORTS.

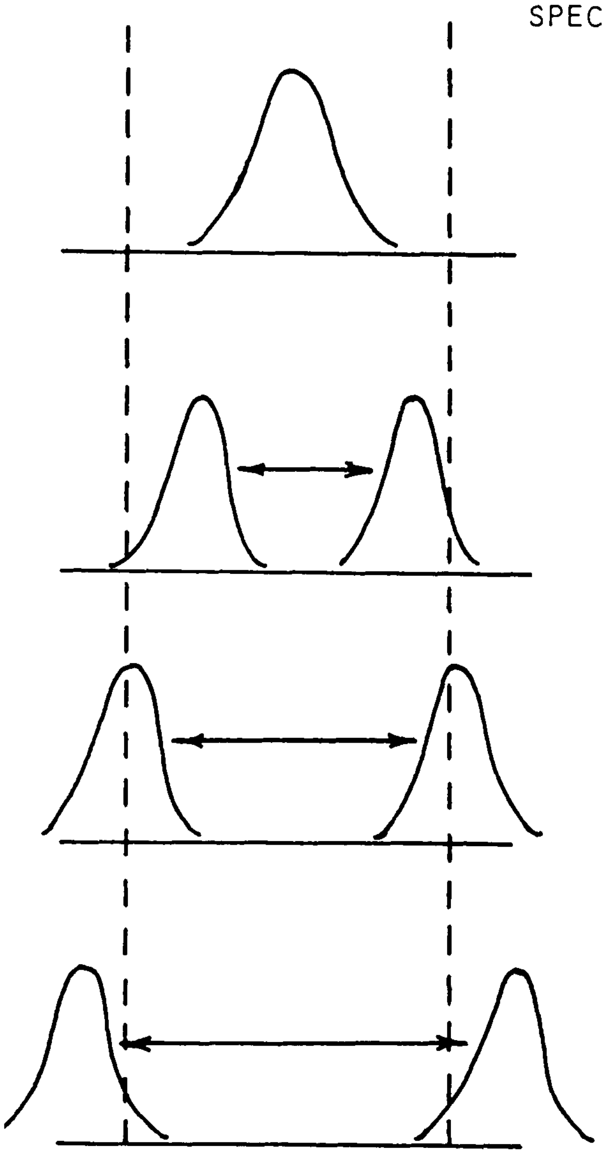
WHEN C_P IS BETWEEN 1.00 AND 1.33, PROCESS IS CAPABLE BUT SHOLD BE SUSPECT AS IT APPROACHES 1.00

WHEN C_P IS LESS THAN 1.00, PROCESS IS NOT CAPABLE.

SOME CAPABILITY TERMS (CONT.)

- K IS A COMPARISON OF THE PROCESS MEAN TO THE MIDPOINT OF THE SPECIFICATION RANGE. IT IS AN INDICATOR OF HOW WELL THE PROCESS IS CENTERED WITHIN THE RANGE. (NOTE: IT MAY NOT RELATE DIRECTLY TO CAPABILITY.)

$$K = \frac{\text{PROCESS MEAN - SPECIFICATION MIDPOINT}}{\text{SPECIFICATION RANGE DIVIDED BY 2}}$$



WHEN K = 0.0, INDICATES PERFECTLY CENTERED (PROCESS MEAN = SPECIFICATION MIDPOINT).

ANY K VALUES ABOVE 0.0, INDICATES PROCESS MEAN ABOVE MIDPOINT. ANY K VALUES BELOW 0.0, INDICATES PROCESS MEAN BELOW MIDPOINT.

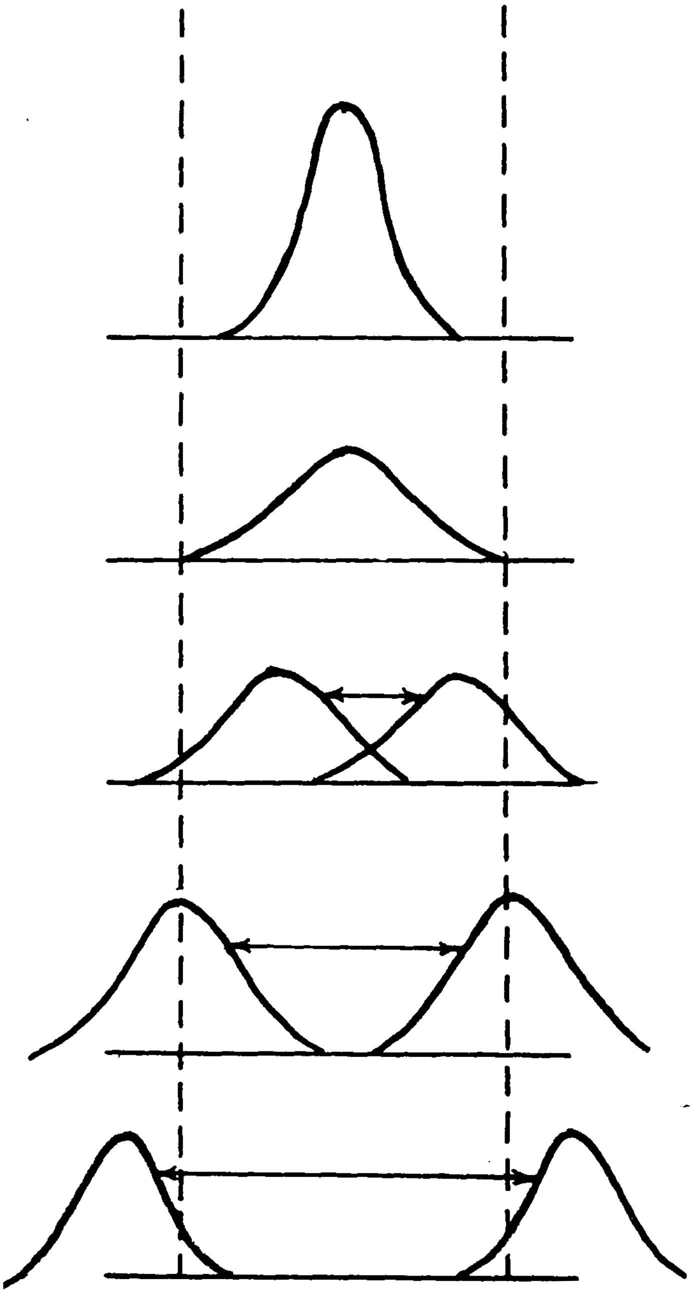
ANY K VALUES +/- 1.0, INDICATES PROCESS MEAN IS CENTERED ON HIGH OR LOW SPECIFICATION LIMIT (50% OF PROCESS WILL BE OUT OF SPECIFICATION LIMITS).

ANY K VALUES ABOVE +1.0 OR BELOW -1.0, INDICATES PROCESS MEAN IS OUTSIDE OF SPECIFICATION LIMITS.

SOME CAPABILITY TERMS (CONT.)

° C_pK IS AN INDICATOR OF CAPABILITY AND CENTERING OF PROCESS VARIATION. C_pK = WHICHEVER IS LESS:

$$\frac{USL - PROCESS\ MEAN}{3\hat{\sigma}} \ \underline{\underline{OR}}\ \frac{PROCESS\ MEAN - LSL}{3\hat{\sigma}}$$



WHEN C_pK IS MORE THAN 1.0, IT INDICATES PROCESS 6 SIGMA LIMITS FALL WITHIN SPECIFICATION LIMITS. A GENERAL GUIDELINE IS THAT A C_pK BETWEEN 1.0 AND 2.0 INDICATES PROCESS CAPABILITY BUT STILL IMPROVEMENT IS REQUIRED TO ATTAIN A GOAL OF 2.0. HOWEVER, INDIVIDUAL CUSTOMERS SHOULD BE CONTACTED FOR SPECIFIC REQUIREMENTS.

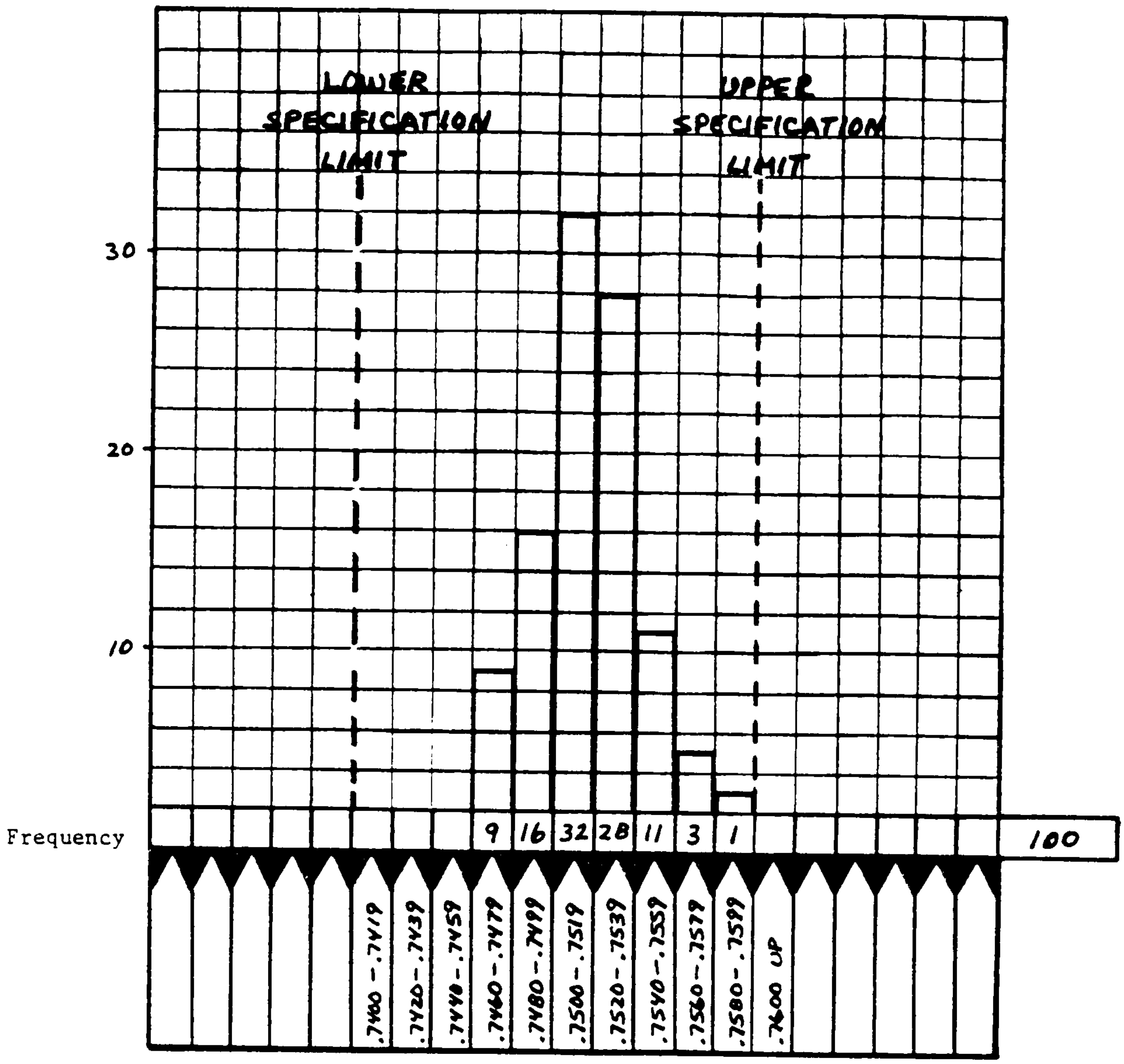
WHEN C_pK = 1.0, IT INDICATES ONE END OF PROCESS 6 SIGMA PROCESS LIMITS FALLS ON ONE END OF SPECIFICATION LIMITS.

WHEN C_pK IS BETWEEN 0.0 AND 1.0, IT INDICATES A PORTION OF 6 SIGMA PROCESS IS OUTSIDE OF SPECIFICATION LIMITS.

WHEN C_pK = 0.0, IT INDICATES PROCESS MEAN EQUALS ONE OF THE SPECIFICATION LIMITS (50% OF PROCESS OUT OF SPECIFICATION LIMITS).

WHEN C_pK IS NEGATIVE, IT INDICATES PROCESS MEAN IS OUTSIDE OF SPECIFICATION LIMITS.

HISTOGRAM CAPABILITY CHART



Date: 4/16

Part #: AEC-5490 Compression

Operation: Coiling

Machine #: 23

Characteristic: Free Length

Dimension/Tolerance: .750 ±.010

Capability Ratio = $\frac{6 \times .00230}{.020}$ = 69.0%

Number of Observations: 100

Average (Mean) = .75156

sigma = .00230

+3 sigma = .75846

-3 sigma = .74466

Other calculations (CP, CPK, Z, etc.): $C_p = \frac{.020}{.0138} = 1.45$

$C_{pK} =$

$$\frac{.760 - .75156}{3 \times .0023} = 1.22$$

$$\frac{.75156 - .740}{3 \times .0023} = 1.68$$

Signed: [signature]

4/18/85

USING SPC TECHNIQUES AND PROCESS IMPROVEMENT

° MUST DEFINE AREA FOR IMPROVEMENT	DATA COLLECTION PARETO ANALYSIS FLOW CHART
° REVIEW PROCESS BEHAVIOR	TALLY SHEET HISTOGRAM RUN CHARTS CONTROL CHARTS CAPABILITY STUDIES
° DETERMINE CAUSES OF BEHAVIOR	CAUSE AND EFFECT SCATTER GRAPH EXPERIMENTS
° DECIDE ACTION TO BE INITIATED FOR IMPROVEMENT	REVIEW AVAILABLE INPUTS
° INITIATE ACTION FOR IMPROVEMENT	NECESSARY CONTROLS
° MONITOR TO VERIFY IMPROVEMENT	RUN CHARTS CONTROL CHARTS PRE-CONTROL

MEASUREMENTS

WHY ARE MEASUREMENTS SO IMPORTANT? - MUST PROVIDE ACCURATE DATA FOR EVALUATION AND DECISION MAKING FOR ACTION.

CALIBRATION - COMPARISON TO STANDARD OF KNOWN ACCURACY.

MEASUREMENT VARIATION - MUST EVALUATE SHORT-TERM GAGE PERFORMANCE AND LONG-TERM GAGE CAPABILITY.

SUGGESTIONS FOR A MEASUREMENT ACTIVITY:

° DO YOU KNOW WHAT DATA YOU SHOULD COLLECT FOR PROCESS CONTROL?

  - WHAT PROCESSES SHOULD BE MONITORED?
  - WHAT CHARACTERISTICS SHOULD BE MONITORED?

° DO YOU KNOW WHAT TYPE(S) OF MEASURING EQUIPMENT IS REQUIRED TO OBTAIN DATA?

  - WHAT EQUIPMENT IS CURRENTLY AVAILABLE?
  - WHERE WILL IT BE USED (ON MACHINE, IN TESTING, AND SO ON)?
  - WHAT IS ENVIRONMENT IN WHICH IT WILL BE USED?
  - WHAT IS REQUIRED ACCURACY AT A REASONABLE COST (1:10, 1:4)?
  - WILL EQUIPMENT MEET YOUR NEEDS FOR DATA COLLECTION?
  - WHAT INSTALLATION IS REQUIRED?

MEASUREMENTS (CONT.)

- IS SELECTED EQUIPMENT ABLE TO BE ROUTINELY (AND EASILY) CALIBRATED AND TRACEABLE TO AN ACCEPTABLE STANDARD (FOR EXAMPLE, NBS - NATIONAL BUREAU OF STANDARDS)?

- WHAT TRAINING IS REQUIRED TO USE MEASURING EQUIPMENT (OPERATOR, SUPERVISORY, TESTING, AND SO ON)?

  - IF TRAINING IS REQUIRED, WHO CAN PERFORM?

- HOW WILL EQUIPMENT BE IDENTIFIED TO INDICATE CALIBRATION STATUS (LAST DATE, NEXT DATE)?

- WHO WILL COORDINATE CALIBRATION ACTIVITY?

  - HOW WILL RECORDS AND CERTIFICATION BE MAINTAINED?

  - HOW WILL ACTIVITY BE MONITORED TO ASSURE CALIBRATION?

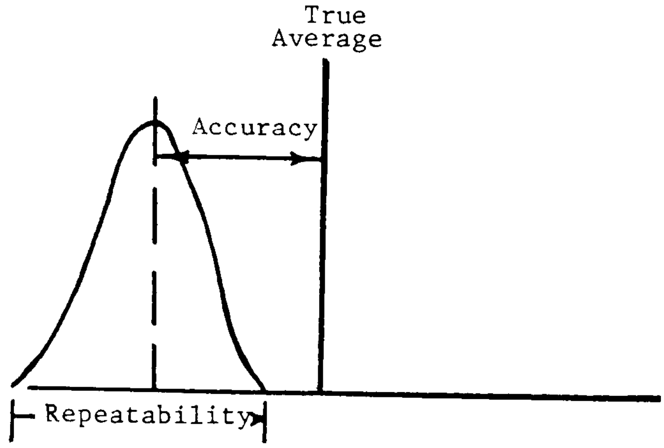
  - HOW WILL EQUIPMENT NOT IN CALIBRATION BE HANDLED?

- DO YOU KNOW WHAT DATA YOU SHOULD COLLECT FOR PROCESS CONTROL?

  - WHAT PROCESSES SHOULD BE MONITORED?

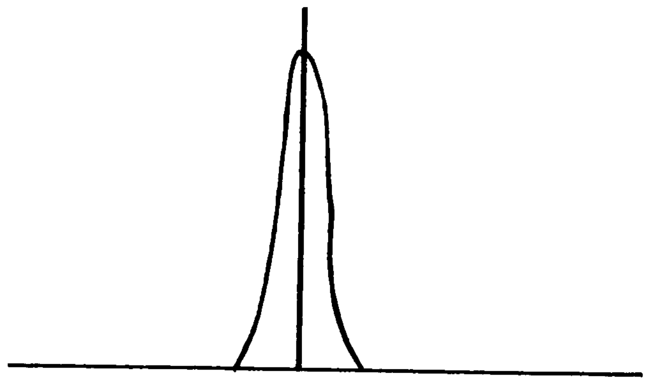
  - WHAT CHARACTERISTICS SHOULD BE MONITORED?

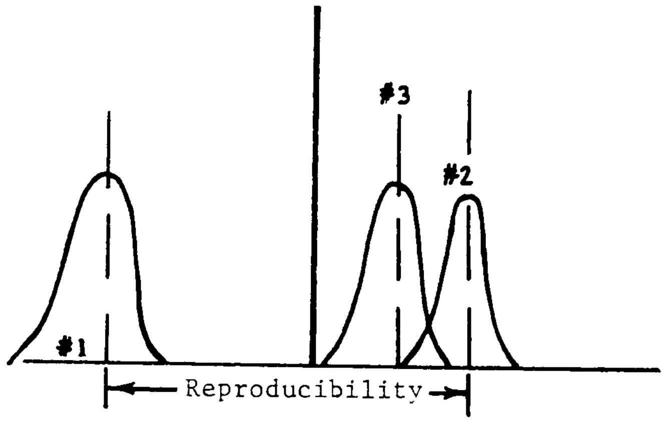
MEASUREMENT VARIATION



ONE OPERATOR, ONE GAGE

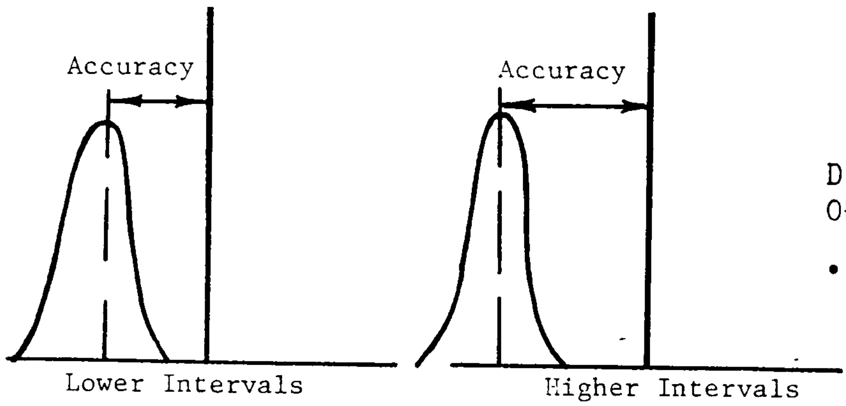
- ACCURACY
- REPEATABILITY





DIFFERENT OPERATORS,
ONE GAGE

- REPRODUCIBILITY



DIFFERENT INTERVALS
ON SCALE, ONE GAGE

- LINEARITY