

## Fusing and SPC

Statistical Process Control • Commutator, SN & Tang Fusing • Six Sigma

by  
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When attempting to produce correctly fused parts that have a constantly valid connection, we must consider the entire fusing process. After we fully understand the process we realize that people are the hardest part of the equation. Therefore, the human factor must be removed as much as possible.

Statistical Process Control (SPC) assists in minimizing human interaction with fusing's production process, by monitoring the natural variation which is statistically predictable. The SPC system is designed to differentiate between predictable trend results and variations that are outside of the predictable.

Before we go any further, it should be understood that SPC is not a quality control system that indicates individual good or bad fused connections. SPC produces data that shows the trend or direction of the fusing process, with regard to the stability of the process' various parameters. With this data, judgments can be made to correct any of the process parameters so that the entire process itself is producing valid connections with few, if any, defects.

The SPC system requires various sensors that collect data which it then processes. It is also possible to set a plus and minus window of acceptance for this data, that would roughly indicate a valid individual connection. If the data falls outside of this

plus or minus window, an alarm can be given or the part being fused can be removed for examination. However, what is described in this paragraph is not the true function of SPC.

### What is Fusing?

Fusing is the joining of low resistance electrical wires, with or without insulation, to each other or a low resistance terminal, without melting any of the metals. The resultant joint will have a very low electrical resistance, and the wire's insulation, if any, will be removed automatically during the fusing process.

Fusing is actually controlled dissipation of heat from fusing electrodes that the fusing process heats

The screenshot shows the 'Main Fusing Control Display' for a Joyal welding system. It features a large blue 'Joyal' logo in the center. On the left, there are several data fields: 'Electrode Counter' (Preset 2000, 587 welds), 'Total Counters' (12,716 Good, 796 Bad), 'Shift Counters' (36 Good, 27 Bad), and 'Firing Pressure' (45 LBS). In the middle, there is a 'Part Data' section with 'Name DS' and 'Part # 1'. On the right, there are control buttons for 'STOP', 'Reset', 'Start Cycle', 'Auto Mode', 'Menu', 'Index on Bad', 'Printer Off', 'Disable Lim', 'Help', and 'Show Limits'. At the bottom, there is a 'Weld Program' section with '0.00 secs.' and 'Weld Program 1'. Below that is a table of 'Current values' for 'Left' and 'Right' joints, showing 'Displ.', 'Force', and 'Current' for both sides. The 'Current' values are 3338 for the left and 3330 for the right.

Parameter	Last Joints Left	Right	Left	Right	Units
Displ.	20.1	18	18.0	19.0	Thous.
Force	62.87	62.62	68.0	67.0	Pounds
Current	2858	2864	3338	3330	Amps

**Main Fusing Control Display**  
This display provides access to all primary system functions including the ability to set the SPC sensors and show the values of the last fused connection.

under controlled pressure. Heat and pressure which are controllable functions of the fusing process can result in other monitorable functions.

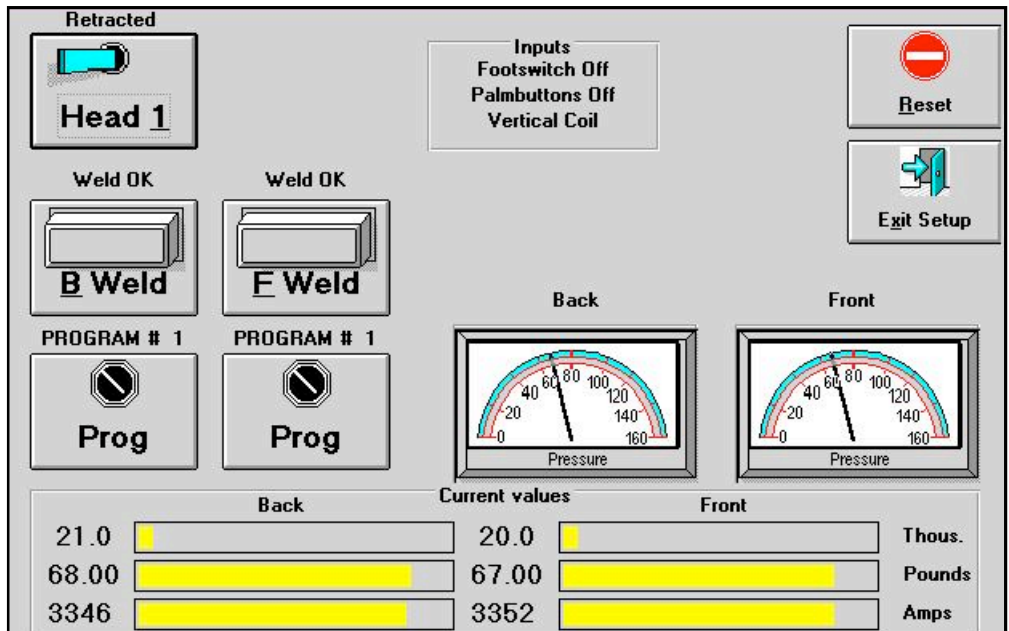
**Fusing - History**

Fusing is a method of joining insulated or un-insulated low resistance wires, through the use of a very simple termination method, which uses a type of resistance fusing machine.

Fusing was originally developed in the early 1950's for use in the manufacture of small universal or D.C. electric motors. At the time, electric motor production for mass markets was quite small, armatures were machine wound, and the lead wires were inserted into slots in the commutator, by hand. The film insulation was manually removed from the wound lead wires, prior to insertion, and the wires were then joined to the commutator. The armature's commutator was then dipped into a molten solder bath. This worked well for low production, and is still being done by some small operations outside the United States.

As production increased and higher temperature insulation systems became available, a faster and more reliable joining method was needed. A fusing system was developed to connect the film insulated lead wires in the commutator's slot, without prior removal of the film insulation. The fusing process automatically removed the insulation. This process is still used today for high performance motors. The method of fusing wires into slots is also used for other limited non-motor applications.

As motor production increased, manufacturers wanted to eliminate the need to place the armature's lead wires into slots. Winding machines were developed to place the wire around pins or



**Setup Screen**

This screen provides the ability to manually operate the fusing machine, and displays real-time SPC sensor values for the last fused connector.

hooks (tang) in the commutator, to which the wires were soldered.

Soldering was then eliminated by the introduction of tang commutator fusing. It is used today to manufacture at least 95% of all the universal or D.C. electric motor armatures produced in the United States, and at least 90% for the rest of the world. Fusing of slotted commutators increases the statistics to over 98% for the U.S. and 95% for the rest of the world. Fusing is the accepted method that is used worldwide.

In 1962, a machine specifically designed for commutator fusing (for both tang and slotted armatures) was Patented (U.S. patent 3,045,103). The commutator fusing machine patented in 1962 is similar to the machinery used today. The new versions differ only in the fusing head's construction and the types of electronics used to control the fusing time, heat and current.

In the early 1950's fusing machines were developed for other than commutator fusing. Most were for terminating bobbin windings to tang terminals, set in bobbin spools. As time went on, tang termination

systems were developed for attaching film insulated wire to just about any component. Today, tang termination can be used instead of most crimped terminals, as well as many applications where crimped terminals cannot handle the job. Normally, Tin is not a required component for tang fusing. This is because the process does not use high enough heat levels to remove the Tin from the tang's joint area. Therefore, a diffusion bond is not normally created during tang fusing.

**SN-Fusing**

SN-Fusing was first developed for joining a single strand of film insulated magnet wire to tinned stranded wire. The film insulation was automatically removed during the fusing process. Later, methods were developed for joining large numbers of magnet wires together using tinned tube like terminals, and for joining magnet wire to tinned pins and terminals. Also, a process was developed for joining large tinned conductors to large commutators on starter and traction motors.

SN-Fusing requires that one of the conductors being joined be coated, or better, plated with Tin. The Tin acts as a cleaner or purifier of the metals that are to be fused. Without the Tin coating, a joint might be obtained, but it would not be strong enough to be effective. It is also possible to use Silver or Gold in the place of Tin, but normally Silver or Gold are not practical, because of their cost.

For a valid joint to be obtained, all insulation and foreign matter must be removed by the fusing process. After this occurs, the Tin wets the un-tinned conductor and purifies the copper (or a copper rich alloy, such as brass) at the joint's interface. The fusing process continues to heat the joint, which results in

the Tin being removed from the joint area. The joint area then consists of ultra-clean copper touching ultra-clean copper (or a rich copper alloy), under heat and pressure. Clean metals clamped tightly together and heated until just before they melt result in a diffusion weld or bond. The metal surfaces fuse and a bond is created.

**Diffusion Bonding** [also called Diffusion Welding]  
 • "A solid state welding process that produces a weld by the application of pressure at an elevated temperature with no microplastic deformation or relative motion of the work pieces".

The definition above is from JEFFERSON'S WELDING ENCYCLOPEDIA, which was published by the American Welding Society of Miami, Florida - USA, in 1997, and is the industry standard definition, as defined by the American National Standards Institute (ANSI) standard A3.0-94, first published in 1940, and most recently revised in 1994.

**Fusing and Surface Adhesion**

Commutator or Tang Fusing is a method of joining low resistance metals with a type of resistance welding machine, but without appreciable distortion

0 = 3332 R =	20 = 3332 R =	40 = 3358 R =	60 = 3343 R =	80 = 3348 R =
1 = 3327 0022	21 = 3357 0025	41 = 3329 0032	61 = 3337 0015	81 = 3328 0020
2 = 3341 X̄=	22 = 3350 X̄=	42 = 3331 X̄=	62 = 3334 X̄=	82 = 3329 X̄=
3 = 3334 3337	23 = 3350 3348	43 = 3339 3337	63 = 3339 3336	83 = 3344 3339
4 = 3349 3337	24 = 3353 3348	44 = 3326 3337	64 = 3328 3336	84 = 3344 3339
5 = 3326 R =	25 = 3358 R =	45 = 3341 R =	65 = 3359 R =	85 = 3352 R =
6 = 3331 0021	26 = 3328 0031	46 = 3338 0015	66 = 3334 0025	86 = 3345 0016
7 = 3347 X̄=	27 = 3353 X̄=	47 = 3336 X̄=	67 = 3359 X̄=	87 = 3341 X̄=
8 = 3326 3332	28 = 3327 3339	48 = 3331 3338	68 = 3359 3353	88 = 3352 3349
9 = 3330 3332	29 = 3329 3339	49 = 3346 3338	69 = 3356 3353	89 = 3357 3349
10 = 3326 R =	30 = 3351 R =	50 = 3352 R =	70 = 3328 R =	90 = 3334 R =
11 = 3351 0027	31 = 3357 0031	51 = 3336 0023	71 = 3342 0015	91 = 3354 0027
12 = 3353 X̄=	32 = 3333 X̄=	52 = 3345 X̄=	72 = 3331 X̄=	92 = 3327 X̄=
13 = 3341 3343	33 = 3330 3339	53 = 3329 3340	73 = 3337 3336	93 = 3345 3342
14 = 3346 3343	34 = 3326 3339	54 = 3340 3340	74 = 3343 3336	94 = 3349 3342
15 = 3343 R =	35 = 3353 R =	55 = 3356 R =	75 = 3331 R =	95 = 3350 R =
16 = 3342 0024	36 = 3345 0011	56 = 3330 0028	76 = 3334 0029	96 = 3350 0021
17 = 3355 X̄=	37 = 3349 X̄=	57 = 3336 X̄=	77 = 3341 X̄=	97 = 3346 X̄=
18 = 3331 3344	38 = 3356 3352	58 = 3328 3337	78 = 3329 3339	98 = 3331 3346
19 = 3349 3344	39 = 3355 3352	59 = 3334 3337	79 = 3358 3339	99 = 3352 3346
Avg. dev. = 9.3097      d2 = 2.326      Xbar100 = 3341.331      # Over limit = 0				
Std. dev. = 10.4997      Sigma = 9.8452      Rbar100 = 22.9000      % Over limit = 0%				
Variance = 110.2435      3 Sigma = 29.5357      CpK 100 = 4.79      # Under limit = 0				
LSL= 3200; USL= 3500      6 Sigma = 59.0714      Cp 100 = 5.08      % Under limit = 0%				

**Data Value Display**

SPC can display the actual data values for the last 100 fused connections of a given parameter (electrical current measurement in this instance). It also displays the X-bar range for each connection in each sub-group. The lower portion of the screen displays SPC calculations for the parameter being displayed

of the parts being joined. Normally, when copper is resistance welded, it is drastically distorted. This does not occur with fusing. What actually happens in commutator fusing and tang fusing (which are not the SN-Fusing processes), is that the parts are heated and pushed together until all the air between them is eliminated, and the high points of one part are pushed into the low points of the other, and vice versa. A surface adhesion contact will then hold the parts together. With SN-Fusing, a diffusion bond is developed. Commutator or tang fusing is not the same

as SN-Fusing. With SN-Fusing there is a metallurgical bond. With commutator or tang fusing there is just a surface adhesion bond, which is physically held together by the fused tang terminal.

The surface adhesion contact is not a weld or diffusion bond. It is a thermo-compression joint, which affects only about 0.0002 of an inch (0.005 mm) of surface depth with no amalgamation or diffusion of metals. As the strength of the joint is not too great, it must be used only with parts specifically designed to be fused, such as a tang terminal, or wire slot. If the interface at the fused joint consisted of ultra-clean copper, which it does not, we might be able to obtain a diffusion bond instead of a surface adhesion or thermo-compression bond, and would not need the tang terminal or wire slot. However, the commutator or most tang terminals are not designed to handle the high temperatures required in SN-Fusing.

As stated above, the wire is heated during the commutator or tang fusing (not SN-Fusing) process. The heat at the surface of the wire can reach from 1,000°F to 2,000°F (537°C to 1,093°C). This heat is usually not sustained for more than 450 milliseconds. Normally, for small wires, 64 to 160

milliseconds is the average time. During this time, insulated wire with any known film or plastic insulation, will be flash vaporized in a puff of smoke.

**Welding or Fusing**

**Welding** • “A joining process that produces coalescence [The growing together or growth into one body of materials ...] of materials by heating them to (an elevated) temperature ...”.

**Resistance Welding** • “A group of welding processing that produces coalescence of the faying [the mating surface of a member that is in contact with ... another member to which it is to be joined] surfaces with the heat obtained from (electrical) resistance of the work pieces to the flow of the welding current in a circuit of which the work pieces are a part, and by the application of pressure”.

The definitions above are from JEFFERSON’S WELDING ENCYCLOPEDIA, which was published by the American Welding Society of Miami, Florida - USA, in 1997, and is the industry standard definition, as defined by the American National Standards Institute (ANSI) standard A3.0-94, first published in 1940, and most recently revised in 1994.

Subgroup size	Current values			Current values		
	16.0	67.00	3357	20.0	68.00	3345
Part #	Left Terminal			Right Terminal		
	Displ.	Force	Current	Displ.	Force	Current
1	.0180	67.00	3332	.0170	68.00	3348
2	.0190	68.00	3327	.0180	67.00	3353
3	.0190	67.00	3341	.0180	67.00	3326
4	.0190	67.00	3334	.0180	67.00	3352
5	.0190	67.00	3349	.0180	67.00	3326
6	.0190	68.00	3326	.0180	67.00	3356
7	.0180	67.00	3331	.0170	68.00	3340
8	.0180	67.00	3347	.0170	68.00	3345
9	.0190	67.00	3326	.0180	68.00	3345
10	.0180	67.00	3330	.0180	67.00	3342
$\bar{X}$ 10	.0188	67.20	3337	.0178	67.20	3341
$\bar{X}$ 100	.0184	67.38	3341	.0174	67.32	3342
$\bar{R}$ 100	.0013	00.95	0023	.0013	00.95	0024
CpK 100	2.03	1.94	4.79	1.42	1.89	4.58
Cp 100	2.98	2.04	5.08	2.98	2.04	4.85
U.S.L.	25	70	3500	25	70	3500
L.S.L.	15	65	3200	15	65	3200

**SPC Data Display**  
 This display shows current data on the last ten fused connections and the SPC calculations for the last 100 connections.

Menu

Graph

Counters

SPC spec totals  
 # in = 100  
 # out = 0

Shift 100

SPC COUNTERS						
Weld Limit Failures						
	Left leg			Right leg		
	Displ.	Force	Curr.	Displ.	Force	Curr.
Under Limit	47	0	4	18	0	1
Over Limit	8	1	0	0	10	0
Cumulative						
# Under Limit	0	0	0	0	0	0
# Over Limit	0	0	0	0	0	0
% Under Limit	0%	0%	0%	0%	0%	0%
% Over Limit	0%	0%	0%	0%	0%	0%
Last 100 welds						
# Under Limit	0	0	0	0	0	0
# Over Limit	0	0	0	0	0	0
% Under Limit	0%	0%	0%	0%	0%	0%
% Over Limit	0%	0%	0%	0%	0%	0%
Total Counters	12716	Good				
	796	Bad				
Shift Counters	36	Good				
	27	Bad				
Electrode Counter	Preset	2000				
		587	Welds			
SPC totals						
	# in spec					
	# out of spec	0				



**SPC Counter Display**

This display shows complete information for the number of failures of each parameter.

The words fusing and welding are used interchangeably by most people. There is a great difference between the two processes and their machinery. Resistance welding (spot welding) is the process of joining metals by locally heating them to their plastic state, and then forging this plastic metal together. The metals being joined are heated internally by passing current through them. The resistance of the metal determines the amount of current and the time the current must be passed, to bring it to its plastic state. Because we want the metals being welded to heat internally, we must make sure that the devices (called electrodes) conducting the current have a lower resistance than those being welded.

When fusing, we want just the opposite. The current carrying devices get hot because they have a higher resistance than the parts being fused. These hot current carrying devices (electrodes) dissipate their heat into the parts that are being fused.

Fusing heats the wire(s) and/or terminals. Any insulation around the wire is vaporized at this time. Theoretically, the wires should not be deformed, but usually they are, slightly. Wire flattened to no more than 200% of its original diameter is acceptable, in most cases. More than this will weaken the wires to a point where they might break from the slightest mechanical movement, such as when a surge of

current is passed through them, or the connection vibrates.

In welding, we need a cooling system to protect the welding transformer, electrodes, and other current carrying devices from any heat transferred from the part being welded. As heat is developed in the parts being welded themselves, the cooling system will not have to absorb the majority of it, as the work will dissipate most of the heat throughout itself. In fusing, the heat is developed in the electrodes and dissipated between the work and the rest of the current carrying system. Therefore, the cooling system must be much larger when fusing versus welding. Heat is developed equally for their sizes, in either a fusing or welding transformer, but a fusing transformer must

have a higher thermal rating, as more heat will travel to it from the electrodes.

In a welding system, pressure must be exerted on the parts to forge them together, when they reach their plastic state. The pressure must be regulated, so that there is just enough to forge the parts, as too much will cause the current to pass through them more easily, without heating them to their plastic state. If "just enough" pressure is used, there will be some surface resistance between the parts being welded, as well as the parts and the electrodes.

When fusing, we must have a higher pressure applied on the work, as we try to force the metals together, without them reaching their plastic state. This means that we are only softening the parts slightly, and relying on the pressure to force them together. Therefore, we must have constant heavy pressure exerted on the parts through the electrodes. Because of this, the fusing head is, of course, much heavier than a welding head, assuming the current carrying capacities are the same.

In fusing, we treat the wires as not being a part of the joint, until we remove the insulation, if any, oxides or foreign matter. This means that we must apply enough current to the electrodes to heat them to a point where they can dissipate enough heat to remove this insulation or foreign matter. As the wire

itself can be damaged, this heating must be carried out in an extremely short time. The only way to do this is by flash vaporization. Normally, a resistance welding system would overheat, if we applied current densities per given time as great as used in fusing, even with the best of heat transfer systems (cooling systems). With fusing machinery, we must use heavier current carrying devices, more iron in our transformers, transformers with higher secondary voltages, and a completely different type of electrode system, in comparison to a resistance welding machine.

Calculations complete for record # 100 of 5000

Count	Displ.	Force	Curr.	Displ.	Force	Curr.	Rec.#
12,804	.0250	66.00	3261	.2780	69.00	3715	1
12,805	.0310	63.00	3170	.2090	79.00	3827	2
12,806	.1630	66.00	3285	.1580	72.00	3554	3
12,807	.1650	71.00	3133	.1550	80.00	3852	4
12,808	.0520	68.00	3264	.2280	80.00	3753	5
12,809	.1340	62.00	3273	.2100	70.00	3619	6
12,810	.1810	59.00	3273	.0670	79.00	4037	7
12,811	.0280	69.00	3191	.0620	70.00	4034	8
12,812	.2150	67.00	3249	.2620	81.00	4090	9
12,813	.1980	62.00	3125	.1180	69.00	3899	10
12,814	.0210	66.00	3134	.1930	79.00	4010	11
12,815	.2290	69.00	3248	.2190	74.00	4037	12
12,816	.0120	72.00	3295	.2500	80.00	3850	13
12,817	.1940	69.00	3244	.2270	77.00	4078	14
12,818	.1210	60.00	3262	.0840	71.00	4083	15
12,819	.0840	70.00	3294	.1350	71.00	3842	16
12,820	.1420	64.00	3269	.1220	77.00	4218	17

X Bar 10	.0872	66.80	3223	.2056	76.00	3740	
X Bar 100	.1203	65.08	3194	.1702	74.50	3805	
R Bar 100	.1546	09.90	0172	.1614	09.15	0527	
Cpk 100	-0.48	0.01	-0.03	-0.70	-0.38	-0.45	
Cp 100	0.03	0.20	0.68	0.02	0.21	0.22	
U.S.L.	.0250	70.00	3500	.0250	70.00	3500	
L.S.L.	.0150	65.00	3200	.0150	65.00	3200	

Start group: [0]

Print

Menu

View Data

Graph All

Graph 100

Date Converter

Date: 8/14/

Daynumber: 227

**Data Editor**

The Data Editor displays all stored SPC fusing parameters for a full production day, as well as any 100 chosen connection parameters, including SPC calculations. The data for each day's production is stored in a unique file which can be accessed at any time.

**Computer Control and SPC**

There are various ways to control a fusing machine's functions. A recent development has been to combine the PC (personal computer) with a commercially available PLC (Programmable Logic Controller). The PLC is used to actually control the machine, while the PLC feeds variable information to the PC. The PC processes this information and acts as a front end for PLC to interface with human operators and/or set-up personnel.

The PLC, such as one manufactured by the Allen-Bradley Company, can easily be programmed and re-programmed by most set-up personnel. These PLC devices use a type of ladder diagram logic, which most electricians can easily understand, and modify.

The PC computer, performs a number of functions. It can act as the PLC's front end, as mentioned above, can show the fusing process graphically in real time, can collect data for SPC (Statistical Process Control) analysis, and can process the collected SPC data to obtain process control and process capability indexes, tables and charts.

**SPC**

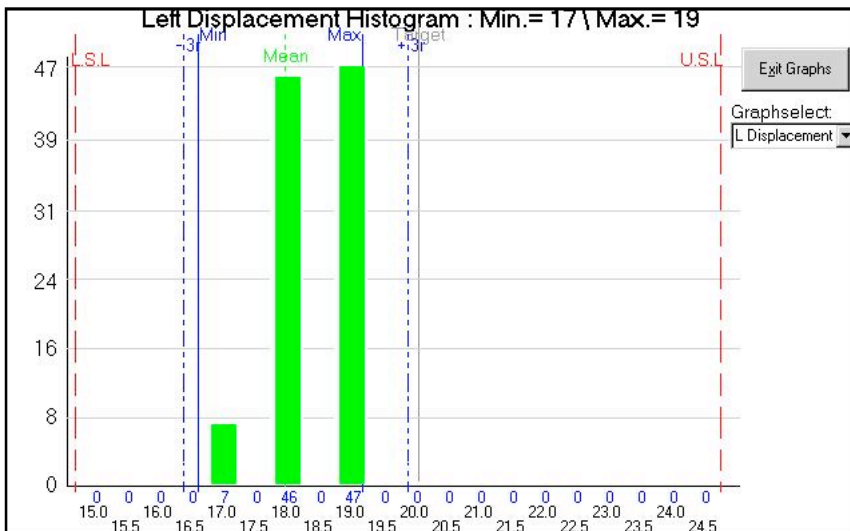
As more firms become ISO 9000 certified, they need to collect statistical documentation for their process' performance and capability. SPC is the most practical method of collecting this data that is used to:

- Define specific and significant process problems
- Establish process standards and tolerances
- Define process capabilities
- Stabilize the process
- Improve the process continually

SPC for the fusing process is normally used to measure variable process results. It is also possible to measure process attribute results.

Variable process results can be compared to a standard and can be measured. The results produce a range of values that can be compared to a plus or minus measurement tolerance.

Attribute results cannot be measured. Instead they are counted, with no value. They are either a go or



**Histogram**

This display shows data that was collected for the last 100 fused connections, in a graphic format, for a given parameter showing the SPC limits and targets.

The above example shows data from one fusing head on a two fusing head system.

machine incorporates a constant current fusing control; a Thermal Monitor/Controller (TM/C), a load cell, an electrode displacement measurement system [Linear Volume Displacement Transducer (LVDT)] , and possibly a cooling water temperature measurement system. The following data can then be easily and accurately collected:

- The actual peak current reached prior to terminating the fusing process;
- The actual total fusing time used during the fusing process;
- The actual temperature reached when fusing was terminated;
- The actual peak fusing electrode pressure reached during fusing;
- The actual final fusing electrode pressure that was reached when fusing was terminated;
- The actual maximum depth the fusing electrode moved below the surface of the unfused parts during fusing;
- The average temperature of the machine's cooling water supply.

no-go, a yes or no, a pass or fail, etc. Normally, the in process or real time monitoring of SPC results for the fusing process does not lend itself to collecting attribute data.

After the fusing process data is collected in real time, it is manipulated by various statistical mathematical equations so that the input data can predict the present and future condition of the process. This data collection and data manipulation is done in the PC and historical data from the process can be stored on the PC's disk, or transferred to some other form of storage.

Process control (Cp) and process capability (Cpk) are the most accurate means of measuring production quality, by using statistical methods. Process control reflects the stability of the process, while process capability measures the built-in consistency of the product that is made by the process. The process is first brought under control by finding and eliminating special reasons for variation. The process is then predictable, and its capability to meet pre-defined expectations can be determined.

The PC would normally collect all or some of the following fusing machine data, assuming the fusing

All of the above listed parameters, plus possibly some others, can be collected for each joint or fused connection. The data for each fused connection can be associated with an armature. The date and time of the actual fusing took place can also be captured. This data can be sent to, say, an output device, such as a printer, where identifying codes can be printed directly on the parts being fused, or to an ink jet printing head that can print data directly on the part being fused. Part numbers or other information can also be printed at the same time.

At any time, SPC data and graphic charts can be displayed on the PC's monitor. Calculations can be performed from the stored data using X-BAR-10, X-Bar-100, R-Bar-100 as well as Pareto Charts, to obtain a Sigma index which will be a guide to production management, as to the relative quality

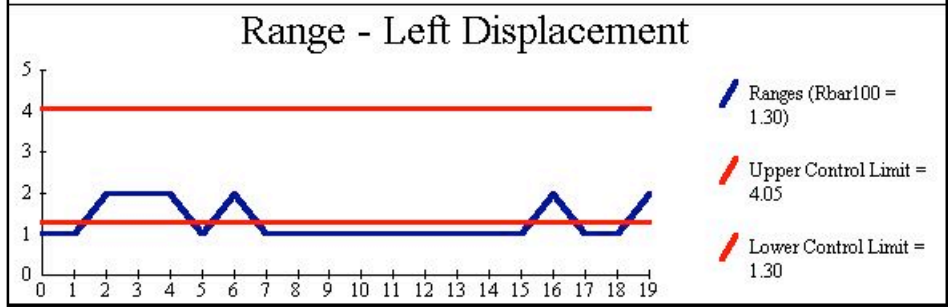
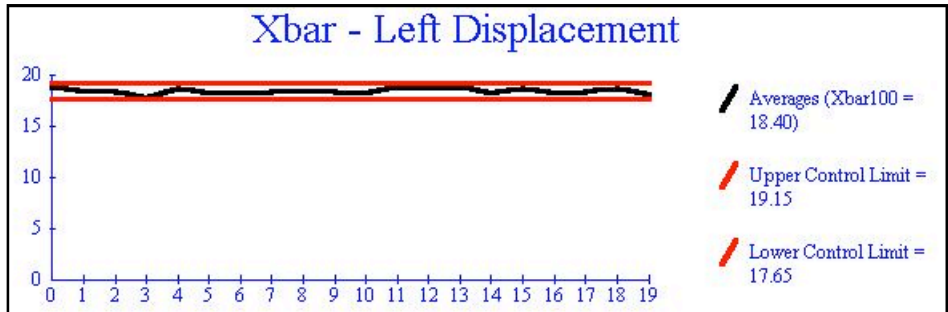
trend of the output from the fusing machine.

The use of a PC computer as the front end of the PLC machine control system results in a number of benefits, but the SPC data capture and data analysis capabilities are added capabilities that are low in cost. As manufacturers attempt to certify their quality control programs, SPC on fusing machines will become essential.

**Pareto Principle**

Vilfredo Pareto (1848-1923) lends his name to the Pareto Chart that is a graphic depiction of a principle used in SPC data displays. This principle, as described by J.M. Juran says:

“The ‘Pareto principle’ ... is a shorthand name for the phenomenon that in any population which contributes to a common effect, a relative few of the contributors account for the bulk of the effect...vital few and trivial many.”



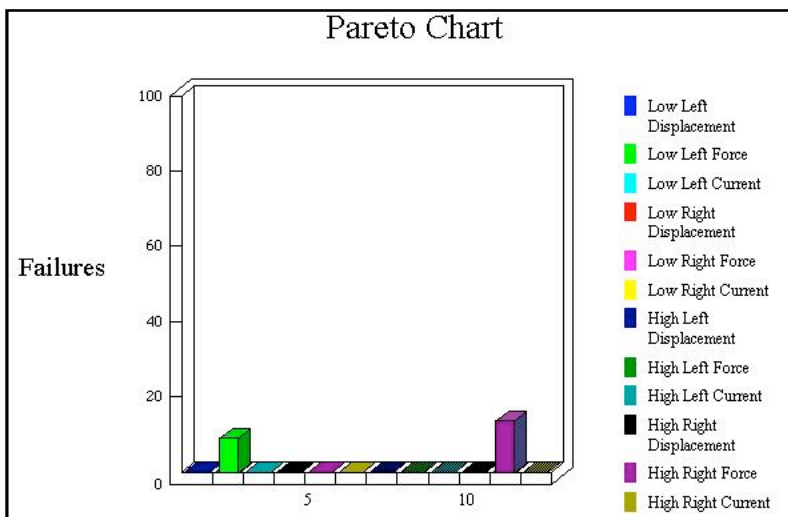
**X-Bar/Range Graph**

The SPC System has full graphing capabilities, and can display the X-Bar and Range graphics of a given SPC sensor's value for the last 100 fused connections.

The above example shows data from one fusing head on a two fusing head system.

Mr. Pareto, a French born Italian economist wrote a thesis entitled “Fundamental Principles of Equilibrium in Solid Bodies” which at the time was meant to refer to his economic observations. These observations apply to just about any type of problem solving.

What this means with regard to fusing is that there can be many causes of a process problem, however, the actual cause is normally found among a relatively few. As an example, 80% of all problems that are found in a process, are caused by less than 20% of all possible causes. The Pareto Chart is used to identify which is the major cause of problems in a process. After investigating the major cause and correcting it, many of the other causes should correct themselves. After the major cause is corrected, the next major cause can be investigated and corrected, and so on. However, the process might be under control by the time one or two causes are corrected.



**Pareto Chart**

This chart graphically displays the failures for each parameter. The above example shows data from two fusing heads on a dual fusing head system.

**Six Sigma - 6σ**

The following is defined by the General Electric Company, a major proponent of the use of SPC in an attempt to meet Six Sigma.

To achieve Six Sigma quality, a process must produce no more than 3.4 defects per million opportunities. An “opportunity” is defined as a chance or non conformance, or not meeting the required process specifications. This means the total process needs to be just about flawless in executing the individual parts of the process.

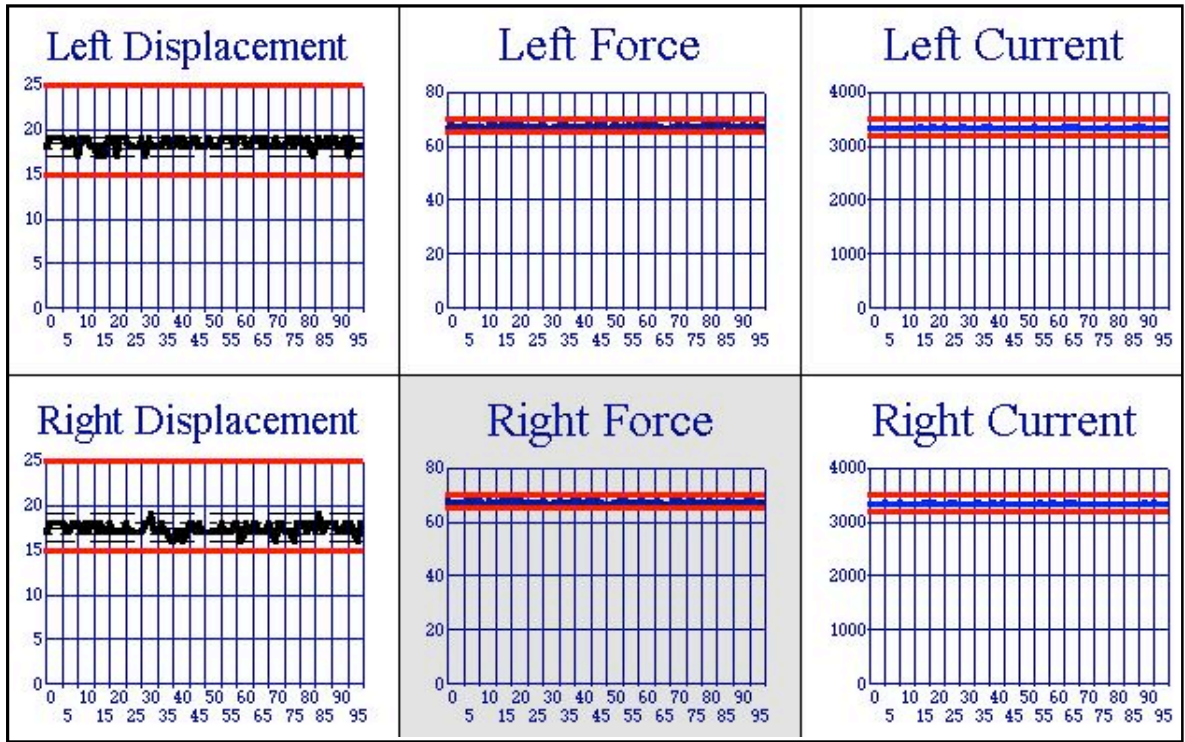
Sigma is the Greek letter [ σ ] which stands for Standard Deviation. Calculations are performed using Standard Deviation statistical mathematical formulas to measure the spread or dispersal between observed data values, in order to see how far the process is diverting from perfection. As an example:

- One Sigma allows a 31.74% deviation
- Two Sigma allows a 4.54% deviation
- Three Sigma allows a 0.27% deviation
- Six Sigma allows a 0.0000034% deviation

**Other SPC Charting**

Other statistical charting and tables are provided in a fusing machine’s SPC system which displays information concerning either individual parts or groups of parts that are being processed. An example of some of the charts and tables that are available are displayed throughout this paper.

As this paper provides only a brief explanation of SPC that is used on a fusing machine, we have not detailed any of the mathematical formulas or statistical theories.



**Graphic Representations**

The SPC system provides full graphic representation of all the measured parameters, such as fusing electrode displacement, force, electrical current, temperature, etc. Full upper and lower limits are also displayed. Click on any of the graphs to display an enlarged detailed view.

The above example shows data from one fusing head on a two fusing head system.