

SELF-DIRECTED PROCESS CONTROL SYSTEM FOR EPOXY MATRIX COMPOSITES

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ABSTRACT

A rule-based, self-directed, process control system is presented for the curing of epoxy matrix composites. The system is adaptable to virtually any polymeric composite system and has been demonstrated on Hercules IM7(graphite)/8551-7 (epoxy). Part thermocouple, vacuum line thermocouple and dielectric sensors were used for control. A programmable autoclave cure control system, the Composite Process Control (CPC) system, available through Aerospace Services and Controls, Inc. (ASC), of Sun Valley, CA was used for the rule-based control strategy programming. It has been demonstrated that the control system developed can process both fresh and aged materials into panels of excellent quality and that it can do so in much less time than required by conventional time-based process cycles. In addition, a novel dielectric sensor wet-out method is introduced as a means by which the materials consolidation can be monitored and controlled.

KEYWORDS: Composites, Cure Monitoring, Automation

1. INTRODUCTION

Standard cure cycle development in industrial practice has consisted of characterizing the matrix polymer using standard techniques such as Differential Scanning Calorimetry (DSC) or Rheometric Dynamic Spectroscopy (RDS) and deriving an appropriate cure cycle from the resulting data. Unfortunately, this approach leads to a great deal of trial-and-error [1] and results frequently will not be applicable to the variability observed in starting materials or component geometry. More recent approaches have been proposed which employ a number of sensors, coupled to a computer, which can be used to alter the cure in real time based upon observed (e.g. thermal and/or rheological) changes taking place in the resin. These newer approaches fall into the category of self-directed control. Two such systems are QPA [2,3] and SECURE [4,5]. The computer programs which monitor and control the process in these newer systems are based upon expert systems. Current limitations of these approaches include: no recovery in the event of sensor failure, difficulties in interfacing them to a user's existing autoclave control system, difficulties in the programming of the expert systems, poor or no means of controlling consolidation, and the research and development nature of these systems not lending themselves to industrial use.

The problem which is addressed in this research is the development of a sensor-based control system. This control system is compatible with standard, robust, industrial process control equipment and, therefore, requires no special equipment. It is a rule-based control system that requires only qualitative information but it does not use an expert system inference engine. It is self-directed so that it responds to material and process variabilities to achieve process goals.

2. EXPERIMENTAL STUDY

The robustness of the controller developed in this research is demonstrated by its capability in handling material variability – fresh vs. aged materials. For this reason Hercules 8551-7 epoxy resin was chosen for its high reactivity and, consequently, significant advancement over short out-time. This section describes the material, its processing requirements and its dielectric property which is monitored during processing, followed by descriptions of the control system software, hardware, and the control strategy.

2.1 Material Characteristics The composite material used for this study is Hercules IM7/8551-7, a graphite/epoxy composite. This resin is a "toughened" 350°F-cure epoxy system. The cure of epoxy matrix composites can be characterized in two basic steps. First, the material's temperature is raised to a point sufficient to melt the polymeric resin without significantly advancing the reaction. While it is in this melted state, the material is consolidated by applying pressure. Second, the temperature is further raised to a point sufficient to cause the epoxide end groups to react, or crosslink, to form a three dimensional network. The temperature is held at this point until the reaction is complete. Figure 1 demonstrates its standard cure cycle for the autoclave cure of a Hercules IM7/8551-7 composite. Pressure is typically applied during the first temperature hold at 250°F when the viscosity of the resin is low as shown in the same figure. Hercules 8551-7 is a highly reactive resin which can advance significantly even over moderate times at room temperature [6]. This advancement results in high melt viscosity and shorter reaction times which restrict flow

and can lead to poor consolidation. Figure 2 demonstrates the effect of this advancement on the dynamic viscosity (G') of the resin obtained by RDS. It is noted that both the melt temperature increases and the gel point decreases with relatively short out-time (e.g. 15 days) at room temperature.

2.2 Dielectrometry Dielectrometry is a fairly accepted means by which the resin state can be monitored in a composite as it cures. The principles of dielectrometry have been discussed by a number of researchers (e.g. [7-9]). Dielectrometers basically measure the capacitance and conductivity (permittivity and loss factor) of the resin. The permittivity (ϵ') is a measure of the alignment of dipoles in an applied electric field, while the loss factor (ϵ'') represents the energy required to align the dipoles and to move free ionic impurities. Other frequently reported dielectric properties which can be monitored and related to resin state are: the magnitude and/or phase of the complex admittance and the "ion viscosity". The ion viscosity is somewhat analogous to the actual viscosity but is based solely on the loss factor and frequency of the dielectric measurement [9]. Generally, the ion viscosity is electrical frequency independent and decreases as the material softens. Similarly, the actual viscosity, as measured by conventional methods (e.g. a parallel plate viscometer), is also mechanical frequency independent and decreases as the material softens. Correlation between changes in the dielectric properties and changes in a material's viscosity during polymerization have been made (e.g. see [8]). A Micromet Eumetric System III [11] dielectric system was used in this investigation. Measurements were made in the "HI-CON" mode using Micromet IDEX sensors. To keep the sensors from shorting out in the presence of graphite fibers, the sensors were covered by a single ply of 180-style glass fabric. The choice of appropriate dielectric parameters to use for the control experiments was made by comparing the various parameters previously discussed with viscosity data obtained via RDS. Figure 3 illustrates dielectric results obtained on a Hercules IM7/8551-7 composite which include the permittivity and loss factor (on log scales) as well as ion viscosity and the phase angle of the complex admittance at various frequencies. Comparisons can be made with actual viscosity data by comparison with Figures 1 and 2. It can be seen that the dielectric ion viscosity results are fairly frequency independent and that the initial melt and solidification events are well represented by the dielectric data. However, these ion viscosity results require several intermediate calculations to obtain. The trends in the $\log(\epsilon')$ and $\log(\epsilon'')$ measurements also represent the effects seen in the actual viscosity quite well. However, the trends in $\log(\epsilon')$ and $\log(\epsilon'')$ are inversely related to the actual viscosity data and their magnitudes are frequency dependent which increase with decreasing frequency. The phase angle data also varies with frequency but represent the actual viscosity trend very well and respond in a similar direction. The phase angle of the complex admittance at 100 Hz were chosen as the parameter to use for control experiments in this study since: (1) it directly resembles viscosity data; (2) its values, which always range between 90 and 0 degrees, can be easily thought of in terms the capacitive vs. resistive behavior of the material and its relation to the materials viscosity, and (3) it is a pure measurement (i.e. it does not require any further calculation).

2.3 Control System Description The capabilities of newer composite cure control systems have advanced to the point where they are capable of self-directed process control, though they are not currently used as such. The Composite Processing Control (CPC) system available from Aerospace Service and Controls, Inc. (ASC) of Sun Valley, CA [10] is one

such system. This CPC system was used as a platform on which control strategy was programmed as rules for self-directed control. The following subsections describe this software controller tool and the hardware it controls.

2.3.1 Control System Software CPC is a modular PC-based, user programmable controller. It allows for easy incorporation of virtually any sensor input which can be processed through a data acquisition board as a voltage or through a serial RS232 digital connection. Through modification of its Programmable Logic Control (PLC) file, its capability can be further extended. CPC is capable of multi-loop "cascade" control which allows for regulating one control parameter (e.g. autoclave air temperature) by measuring another (e.g. part temperature). The control strategy is expressed as rules in CPC's CUREFILE. These rules in the CUREFILE are programmed in "segments" where specific criteria ("watch variables") must be met before control is passed to the next segment. Conventional time-based cure cycles can be programmed using time as the watch variable. However, in the case of self-directed control, the watch variables are typically sensor-based. For example, it is possible to specify that a dielectric loss factor must reach a predetermined value or trend before moving to the next segment. The watch variables also make it possible to revert back to a conventional time-based control scheme in the event of sensor failure. In addition, the software has a number of built-in features such as trending analysis functions and temperature-rate-correction control. The trending analysis functions can identify PEAKs, VALLEYS, FLATs, RISEs and FALLs in any parametric value. This is done by first defining a moving window in time then computing the standard deviation for each third of the window and the average over the entire window. The differences between the average and deviations are then used to identify the trend types (e.g. FLAT, PEAK, etc.) [10]. This feature enables the system to make proper control decisions in the presence of noise or when absolute values of sensor responses vary from process to process. The temperature-rate-correction control forces all part temperatures to be within a specified limit by automatically adjusting the heat-up and cool-down rates. This allows for optimal heat-up and cool-down rates in a process while avoiding unacceptable thermal gradients/exotherms. CPC also has built-in features which force the system to recover and/or sound alarms when any specified variable's value is exceeded at any point in the process. The CPC system scans all the input channels every two seconds. The option to turn on or off six-point moving averages can be used on all of the input channels. Sensor data and equipment status information are saved to an output file at user defined intervals. An interval of 30 seconds was used for all cases presented herein. Several special modifications to the basic CPC software were additionally made to satisfy the needs of advanced sensors. These modifications included computation of the dielectric permittivity and loss factor on a log scale and implementation of a "temperature-add-gain" feature. The temperature-add-gain adds an increment to the temperature set point which is proportional to the rate of change of the dielectric phase. This feature was added to cause the system to keep the material in a melted state during consolidation (pressurization).

Three basic files are required to initiate a process run on the ASC autoclave using the CPC software. These files are; the PARTFILE, the RUNFILE, and the CUREFILE. The PARTFILE simply assigns the part thermocouples and various vacuum lines to the parts being processed. The RUNFILE contains information on the run (material type, operator, etc.), defines the files for data recording, and defines the CUREFILE name for the run. The CUREFILE is where the

control strategy resides. A sample CUREFILE is shown in Figure 4. A complete description of the CUREFILE programming is provided by ASC in the CPC manual [10]. However, a brief description is included herein for reference.

The CUREFILE is divided into numbered segments. The process proceeds through the segments in numerical order. The process will be held in a given segment until a specific criterion (watch variable) is met or until a specified time has elapsed. Two different watch variables can be simultaneously stated. These watches can also be logically coupled using "and/or" type statements. The temperature can be controlled on specific part thermocouples or on an average value of all those assigned. Temperature and pressure rates and goal values can be specified in each segment. The cascade control allows for control of the air (autoclave) temperature based upon the value of another (e.g. part) temperature. The values of "cascade in/out" specify the amount of change in air temperature set point required per deviation in the other (e.g. part) temperature. Specifying a value of A allows the system to automatically choose the values, while specifying X turns off a given parameter's effect. The "trend rec" parameters specify the parameters for which the trend (e.g. PEAK, FLAT, etc.) recognition feature is to be applied to. As previously mentioned, the temperature-rate-correction control, when turned on, will automatically reset the heat-up and cool-down rates such that the "max T/C delta" is kept within the limits specified. In all cases, a blank parameter field in a segment simply assumes the value of the field in the previous segment. The use of this file will be further illustrated in the Results and Discussion section of this paper.

2.3.2 Control System Hardware Autoclave process runs were made at GE Aircraft Engines in Cincinnati, OH using an ASC autoclave (Serial # 45) which was purchased primarily for R&D purposes. The autoclave hardware was modified slightly from its original configuration to include the capabilities to monitor and control the cure process using a variety of advanced sensors. The autoclave was originally purchased with four type K thermocouple and three additional pass-through ports through which additional sensors could be added. It is rated for pressures up to 800 psi and temperatures up to 1000°F. The working space of the autoclave is 18"×18"×36". The modifications to the autoclave itself consisted of adding four (3-pin) inputs (for two dielectric sensors and two Hall-effect sensors) and six type-J (2-pin) thermocouple inputs (for two thermopiles, two additional type-J thermocouples and two Curite pressure sensors).

The CPC software resides in an IBM AT-type personal computer. CPC reads all sensor inputs except the dielectric data through 12-bit Kiethly-Metrabyte data acquisition boards. The dielectric data are obtained from a Micromet dielectrometer interfaced via an RS232 serial port using text-string (ASCII) data transfer. The programming commands of the Micromet system are described in its users' guide [11].

2.4 Part Preparation Prior to the start of a process run the material was first laid-up and vacuum bagged according to standard practices. Forty plies of (0,90)s laminates were used in all cases considered herein. Two Micromet IDEX type dielectric sensors were used for the process control. The first dielectric sensor was covered by a single ply of 180-style glass fabric to prevent it from being shorted out by the graphite fibers in the composite and was placed face-up in the center of the laminates. This first sensor was used to monitor and

control the resin state of the material being processed. The second dielectric sensor was placed face-down above the material and above two 120-style glass fabric bleeder plies. This second dielectric sensor was used to determine whether proper consolidation had been achieved which was indicated by the detection of sensor wet-out as resin was squeezed through the bleeder plies. Note that the choice of two bleeder plies was somewhat arbitrary but were observed to provide satisfactory bleed for the 40-ply laminates. In addition to the dielectric sensors, three part thermocouples were also used in the process. The first thermocouple was placed one ply from the top; the second, in the center; and the third, one ply from the bottom of the laminate. These three thermocouples were used to control the heat-up and cool-down rates to keep the temperature gradient within acceptable limits. In addition to the dielectric and thermocouple sensors, the vacuum line temperature was monitored to watch for bag leaks. Following lay-up and bagging, the part was placed in the autoclave and the sensor outputs checked for proper operation. Next, the run was started and the CUREFILE executed.

2.5 Control Strategy The actual use of this system to control the process of real world materials requires the development of the control strategy. The strategy used to control this process is based on the "spec" process for this material with accommodations made for: (1) differences in melt viscosity, caused by variations in out-time, which would require temperatures and/or pressure adjustments for proper consolidation; (2) differences in part thickness which require different heat-up rates to maintain acceptable part thermal gradients; and (3) differences in the amount of time required to fully cure (crosslink) the material, again stemming from out-time advancement differences. This cure schedule is programmed in such a way that it defaults to a more-or-less conventional (spec) cure schedule in the event sensors fail. The actual control process is performed in three basic sequences: **MELT**, **CONSOLIDATION** and **CROSSLINKING**. The control logic of these sequences are flow-charted in Figure 5 which, along with the CUREFILE in Figure 4, should be referred to for the following descriptions.

The first segment of the CUREFILE represents the **START-UP** sequence of the process where the initial system parameters are set and the blower, heaters, cooling, and vacuum enabled. In this segment the temperature is initially set to CURRent, the temperature control is set to control on the average (MEAN) value of the part thermocouples, and the vacuum is set to full (-30 in-Hg) to aid in removal of any residual volatiles in the prepreg. The two dielectric sensors are assigned for trending analysis on the phase angles of their complex admittance at 100 Hz. The center dielectric sensor (assigned as PATT1) is given a window height of 10° and a width of 5 minutes for trending. The top dielectric sensor (assigned as PATT2) is given a 10° × 10-minute trending window. The values for these windows has been determined by examining the dielectric outputs of several process monitoring runs [12]. A maximum part temperature gradient of 15°F is specified and the temperature-rate-correction control feature is also turned on in this sequence. Although only a single thickness is considered in this case, the use of this feature will slow down the heat-up rate as necessary to keep all part temperatures to within 15°F. The 15°F value was chosen on the basis that it should be achievable by the control system while keeping the gradients relatively low.

Segments 2 and 3 constitute the **MELT** sequence of the process. In this sequence, the temperature is ramped to 220°F unless the mid dielectric sensor detects a minimum in

viscosity. The temperature-rate-correction control, along with a goal temperature rate of 5° F/min (which is slightly higher than actually obtainable), ensures that the material will be heated as fast as possible while keeping the differential less than 15°F. The viscosity minimum is detected by a FALL followed by a FLAT in the dielectric reading, or followed by a VALLEY if this event occurs in less than 5 minutes which is the width of the trending window. If the sensor fails to detect a viscosity minimum (as may occur if the sensor does not fully wet out) the temperature will not be raised past 220°F. The value of 220°F is consistent with the maximum safe melt temperature found by reviewing rheometric test data (see Figure 2) on both fresh and aged materials. It has been observed that the material, especially when fresh, may melt at lower temperature. In such case, the part is held at a lower temperature. After the melt viscosity minimum has been detected, the temperature is set to its CURRENT value (a value of 220°F or lower) and control is then passed to the **CONSOLIDATION** sequence of the process.

Segments 4 and 5 constitute the **CONSOLIDATION** sequence of this process which is illustrated in the flow chart in Figure 5. The previously described temperature-add-gain feature is turned on with a rate of 0.1 (adding 0.1°F to the set point temperature per degree rise in dielectric phase angle). This helps the material to remain in a melted state while consolidation takes place. The value of 0.1 was determined from the results of previous process control runs [12]. In this sequence, pressure is first applied at a rate of 5 psi/min with an ultimate goal of 200 psi. The 5 psi/min rate allows the material time to flow as pressure is applied. The vacuum is released and set to vent when the pressure reaches a value of 25 psi (per the process requirements of this material system). Pressure is increased until the top dielectric sensor wets out as indicated by a FALL in the dielectric phase angle. When either this FALL has occurred, or when 200 psi has been reached, the pressure is held at its CURRENT value and control is passed to the **CROSSLINKING** sequence of the process. Note that the spec process for this material calls for a pressure of 100 psi. However, process monitoring runs indicated that higher pressure, especially in the case of high out-time material, may be required for consolidation. In addition, the upper limit value of 200 psi is consistent with the capabilities of most industrial autoclaves.

Segments 6 through 8 constitute the **CROSSLINKING** sequence of the process. In this sequence the temperature is ramped, as fast as possible, to 350°F (noting that the temperature-rate-correction control with a maximum part delta of 15°F is still in effect) which is a required crosslinking temperature for this material system. Once reached 350°F, the temperature is held constant until crosslinking is complete. Crosslinking completion is identified through a FLAT in the center dielectric sensors phase angle. The time span for this hold is set for a minimum of 30 minutes and a maximum of 90 minutes. The initial 30-minute hold in segment 7 has been found necessary to allow the center dielectric phase angle trend to register as a RISE coming out of the **CONSOLIDATION** sequence. Note that the dielectric phase trending window dimensions have been changed to 3° × 30 minutes back in segment 4. It is necessary to change the window size before making the control decision in order to give the system time to reset on data within the new window. Previous process monitoring experiments showed a FLAT within a window of size 3° × 30 minutes was a good indicator of end-of-cure [12]. The maximum total time of 90 minutes at 350°F has also been determined as acceptable from

previous RDS experiments (see Figure 1) and previous process monitoring runs. Once this sequence has been completed control is passed to the **COOL-DOWN** sequence of the process.

Segments 9 through 11 constitute the **COOL-DOWN** sequence of the process. In this sequence the material is cooled as fast as possible, again keeping the maximum delta within 15°F, to room temperature. The delta is controlled within this **COOL-DOWN** to avoid undesirable thermally induced stresses in the part which are a potential cause of ply cracking. The pressure is not released until the temperature had fallen below 125°F to avoid damage to the autoclave exhaust system by the flow of hot gas.

3. RESULTS AND DISCUSSION

The process control logic just described has been demonstrated for the cure of both fresh and aged (15 days room temperature out-time) Hercules IM7/8551-7 panels. The results are discussed in the following subsections.

3.1 Fresh Material Results The fresh material results are shown in Figure 6. In this run, the vacuum temperature showed a slight rise during the initial ramp between about 100°F and 150°F. This was most likely due to the evolution of water and/or solvent, noting that full vacuum was in effect during this ramp. The temperature-rate-correction control automatically slowed the heat-up rate from the specified value of 5°F/min to about 4°F/min. The center dielectric sensor showed a steep drop (FALL) in phase angle at about 150°F which was taken by the control system as the initial melt/wet-out. The minimum (FLAT) did not occur until the temperature reached just above 200°F. At this point the **CONSOLIDATION** sequence began with the start of pressure application. The temperature-add-gain feature, which keeps the material melted during consolidation, slightly cooled the material at first then maintained the temperature at a nearly constant temperature of about 200°F. The top dielectric sensor started at a low value and slowly rose during the initial ramp. This was most likely due to moisture or solvent coming in contact with the sensor and its eventual dry-out. This top dielectric sensor indicated a FALL when the pressure reached about 125 psi (where it was held for the remainder of the process), corresponding to resin wet-out through the bleeder plies. This occurrence then completed the **CONSOLIDATION** sequence of the process. The **CROSSLINKING** sequence was then initiated and the temperature was raised to 350°F. The center dielectric phase angle began to rise at about the point where the material reached the 350°F hold temperature. This center dielectric phase angle did not level off (reached a FLAT) until just over 60 minutes into the hold. This FLAT in phase angle indicated end-of-cure and the **COOL-DOWN** sequence then proceeded as expected.

The overall process control system performed very well and produced a panel of excellent quality, as indicated in Table 1, by comparison with a panel made by the spec process and by comparison with cured panel specification values [12]. In addition, the CPC-controlled process run took considerably less time than the spec process run as indicated by the differences in the "Run Time" values. The 120-minute crosslinking hold time in the spec process is also longer than needed as indicated by the differences in "Cure Time".

Table 1
Hercules IM7/8551-7 Panel Quality Comparisons

<u>Run ID</u>	<u>OutTime</u>	<u>Process</u>	<u>Tg (°F)</u>	<u>Fiber v%</u>	<u>Void v%</u>	<u>Run Time</u>	<u>Cure Time</u>
E052594R	48 Hours	SDC	323	63.3	0.3	130 min	60 min
E053194	48 Hours	Spec	334	57.4	0.0	336 min	120 min
E052694	15 Days	SDC	329	56.7	0.0	134 min	46 min
E053194	15 Days	Spec	328	63.8	0.1	336 min	120 min

SDC: Self-Directed Control

Spec: Spec Cycle

3.2 Aged Material Results The same control rules used for the fresh material were used for curing a 15-day aged material. The results are shown in Figure 7. In this run, the vacuum temperature did not show a rise during the initial ramp between about 100°F to 150°F as was the case for the fresh material. Again, the temperature-rate-correction control automatically slowed the heat-up rate to about 4°F/min. The center dielectric sensor showed a gradual drop (FALL) in phase angle from the start of the temperature ramp. The minimum (FLAT or VALLEY) did not occur until the temperature was into the 220°F hold which then began the **CONSOLIDATION** sequence with pressure application. Here we see that the aged material required a higher temperature to melt and that a condition different from that in the previous case caused a transition to the next sequence. The temperature-add-gain feature functioned as it did in the previous case. The top dielectric phase angle had a larger FALL at the beginning and then rose back up during the 220°F hold which again is attributed to volatiles coming in contact with the sensor and then drying out. This top dielectric phase angle then remained nearly constant without a FALL, which in the previous case caused a hold at a pressure of 120 psi. Instead, the pressure continued to ramp up to the maximum permitted pressure of 200 psi which ended the **CONSOLIDATION** sequence of the process. The temperature was next raised to 350°F in the **CROSSLINKING** sequence. The top dielectric phase angle did not show a large FALL until well into the 350°F ramp. This late detection of flow at the top was due to greater advancement of the aged material. While the center dielectric phase angle began to rise at about the same temperature as in the previous case, it took a shorter time of 45 minutes to reach the FLAT, or end-of-cure. This shorter cure time is expected for an aged material.

The same control program as in the previous case now carried out a different cure cycle as a consequence of the self-directed action of the controller to compensate for the higher advancement of the aged material. As was in the previous case, the controller performed well and produced a panel of excellent quality with much less time than the spec cycle as can be seen in Table 1.

4. SUMMARY AND CONCLUSIONS

The development of a sensor-based, self-directed control system, compatible with standard, robust, industrial composite process equipment, has been addressed in this research. The system has been demonstrated by successfully curing fresh and aged Hercules IM7/8551-7 composite panels with the same rule-based control program in a CUREFILE of the CPC

system. The controller was able to identify differences in melt temperature, melt viscosity, and consolidation through the use of two dielectric sensors and directed heating and pressure application accordingly, which resulted in different cure times and pressure levels for these two panels. The aged material required higher temperature, higher pressure and less time to cure as expected. Both panels were of excellent quality and were processed in significantly less time than that of a spec process.

The advantages of this system, over previous self-directed control systems, are: (1) it is based on supported industrial hardware and software, (2) it is easily implemented and programmed, (3) it uses trend recognition capabilities to allow for qualitative assessment of the material's state, (4) it can be easily modified to accommodate almost any sensor, (5) it introduces a dielectric sensor wet-out measurement to control consolidation, and (6) it is able to revert back to a conventional cycle in the case of sensor failure. In addition, it combines all the above with the "episode" logic, heating rate control, temperature/pressure limit control, feedback on the materials viscosity allowing control of the viscosity minimum, and fault recognition found in other systems.

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**ASC 18" x 18" x 36" R&D AUTOCLAVE A-45
CUREFILE PRINT-OUT**

CPC SYSTEM by Aerospace Service & Controls, Inc.

Time of print-out : 11:52:40
Date of print-out : 05-25-1994
Operator : Matt Buczek

Sensor/Input Abbreviations:

TSET - Temperature Setpoint AIRTC - Air temperature t/c
PSET - Pressure setpoint PRESS - Pressure
VSET - Vacuum setpoint SVAC - System vacuum
PTCx - Part t/c #x WACHx - Status for Watch #x
MONx - Vacuum Monitor #x SEG - Current curefile segment

CUREFILE NAME : 8551-7.CUR
CURE DESCRIPTION : SELF-DIRECTED CONTROL

CUREFILE COMMENTS

	Seg1	Seg2	Seg3	Seg4	Seg5	Seg6	Seg7	Seg8	Seg9	Seg10	Seg11
Seg Time (or END)	----	----	----	----	----	----	30M	----	----	----	END
Temp Control T/C	MEAN	----	----	----	----	----	----	----	----	----	----
Rate	5	----	----	----	5	----	----	10	----	----	----
Value	CURR 225	----	----	CURR	----	350	----	70	----	----	----
Cascade In	----	A	----	X	----	A	X	----	100	----	----
Cascade Our	----	A	----	X	----	A	X	----	200	----	----
Pressure Rate	----	----	5	----	----	----	----	----	10	----	----
Pressure Value	0	----	205	----	CURR	----	----	----	0	----	----
Vacuum Value	-30	----	----	0	----	----	----	----	----	----	----
Watch #1	AIRTC	MEAN	PATT1	PRESS	PATT2	MEAN	----	PATT1	AIRTC	PRESS	----
Criterion (if)	<100	>220	=FLAT	>25	=FALL	>345	----	=FLAT	<125	<5	----
Action (then)	AND	OR	OR	GO	OR	GO	----	GOGO	GO	GO	----
Time	----	----	----	----	----	----	----	60M	----	----	----
Watch #2	PHAS1	PATT1	PATT1	VTC3	PRESS	VTC3	----	VTC3	----	----	----
Criterion (if)	>75	=FALL	=VALL	>150	>200	>200	----	>200	----	----	----
Action (then)	GO	GO	GO	ALARM	GO	ALARM	----	ALARM	----	----	----
Time	----	----	5M	----	5M	----	----	5M	----	----	----
Blower Fan	ON	----	----	----	----	----	----	----	----	----	OFF
Pressure Enable	ON	----	----	----	----	----	----	----	----	----	OFF
Heat Enable	ON	----	----	----	----	----	----	----	----	----	OFF
Cooling Enable	ON	----	----	----	----	----	----	----	----	----	OFF
Vacuum Enable	ON	----	----	----	----	----	----	----	----	----	OFF
SUP Line Part #	ALL	----	----	----	----	----	----	----	----	----	----
SUP line action	VAC	----	----	VENT	----	----	----	----	----	----	----
Max Part T/C Temp	300	----	----	----	400	----	----	----	----	----	----
Time dead - band	30S	----	----	----	30S	----	----	----	----	----	----
Max Air Temp	400	----	----	----	500	----	----	----	----	----	----
Time dead - band	30S	----	----	----	30S	----	----	----	----	----	----
Max Part T/C Delta	15	----	----	----	----	----	----	----	----	----	X
Time dead - band	10M	----	----	----	----	----	----	----	----	----	----
Correction Control	ON	----	----	----	----	----	----	----	----	----	OFF
Micromet Freq #1	100	----	----	----	----	----	----	----	----	----	0
Micromet Freq #2	100	----	----	----	----	----	----	----	----	----	0
Temp Add Gain	X	----	0.1	----	X	----	----	----	----	----	----
Micromet A/D Ratio	80	----	----	----	----	----	----	----	----	----	----
Trend Rec#1 Input	PHAS1	----	----	----	----	----	----	----	----	----	----
Window Time Span	5M	----	30M	----	----	----	----	----	----	----	----
Vert. Sensitivity	10	----	3	----	----	----	----	----	----	----	----
Trend Rec#2 Input	PHAS2	----	----	----	----	----	----	----	----	----	----
Window Time Span	10M	----	----	----	----	----	----	----	----	----	----
Vert. Sensitivity	10	----	----	----	----	----	----	----	----	----	----

Figure 4: CPC CureFile Example for the Cure of Hercules IM7/8551-7