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DEVELOPMENT OF AN AUTOMATED
FOAM PROCESSING SYSTEM

Final Report

J. B. Gallaher, Project Leader

Project Team:
R. B. Mayfield
J. W. Steele

Published January 1978

MASTER

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**Kansas City
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DEVELOPMENT OF AN AUTOMATED FOAM PROCESSING SYSTEM

BDX-613-1691, UNCLASSIFIED Final Report, Published January 1978

Prepared by J. B. Gallaher, D/845.

An automated polyurethane foam processing system was evaluated for use in the production of electronic product at Bendix Kansas City after it was discovered that inadequate mixing of the foam constituents occasionally yielded dimensionally unstable foam. The automated system developed during this study has proven superior to the previously used methods while cutting flow time and material usage.

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**A prime contractor with the United
States Department of Energy under
Contract Number EY-76-C-04-0613**

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SUMMARY

Processing variables in the polyurethane foam encapsulation procedure on an electronic assembly timer occasionally yielded foam which was dimensionally unstable. This change in size was large enough that the affected timers would not meet gage requirements and had to be reworked. This instability was indicative of a marginal process. A thorough investigation of the problem determined that inadequate mixing of the two constituents of the foam was the cause. To eliminate the cause of the marginal process, requirements were defined which were used as guidelines in specifying the necessary equipment. This specification was then issued to suppliers for quotes. Once the quotes were received, the capabilities of the different foam processing systems were reviewed to assure conformity to the specification.

A foam processor was purchased from Ransburg Corporation for use on the timer. This particular piece of equipment was chosen and evaluated to assure that it would process material within existing specifications. Data presented here proves that the equipment exhibits capabilities superior to the current manual procedures.

Process data gathered during the study indicates that the equipment decreases product encapsulation flow time by 80 percent and cuts material usage by 50 percent.

DISCUSSION

SCOPE AND PURPOSE

The automated foam processing equipment shown in Figures 1, 2, and 3 was purchased to solve a problem encountered during the post-encapsulation environmental testing of the timer. Investigation determined that the problem was caused by inadequate mixing of the foam components in the encapsulating compound.

Although the problem was solved for the remainder of the program by making minor adjustments in the mixing specifications, occasional units were still rejected because of inadequate mixing of the encapsulant. The purpose of this endeavor was to develop a process for encapsulating the unit in rigid polyurethane foam using an automated foam processing machine. The equipment purchased as part of this endeavor proved superior to current manual procedures and applying these new capabilities was a goal of this project.

PRIOR WORK

Timers were routinely subjected to stringent environmental tests following encapsulation. As part of the testing procedure, the units were heated to 94°C and then electrically tested. Following these tests, the timers were gaged to check the mechanical dimensions. It was found that the encapsulation on some units expanded during the heating process and would not fit the gage.

Investigation revealed that this expansion occurred only when operators of the mixing machine were not scraping the sides of the mixing container during the mixing process to ensure that all the encapsulant components were properly mixed. This resulted in some areas of the foam being either resin rich or resin depleted. The concentration of improperly catalyzed foam caused the thermal instability.

A temporary solution to the problem was to write into the mixing procedure a requirement that the sides of the mixing container be scraped continually during the mixing process. However, occasional units still came through production with encapsulant that bulged during electrical testing. A more permanent solution to the problem had to be found.

With the assistance of the General Electric Neutron Devices Department, a specification was evolved which defined a foam processing system tailored to Bendix needs. To be certain of the

Figure 1. Automated Foam Processing Equipment

equipment's performance, an acceptance testing program was incorporated into the specification which would require the manufacturer to use Bendix-supplied material to prove-in the equipment (Appendix).

The equipment met all of the acceptance criteria and was subsequently shipped to Bendix. At this point, an effort began to determine the effects of machine processing and to develop a production procedure.

ACTIVITY

System Description

Figure 4 shows the material flow path during the recirculate mode of the system. This is the standby mode in which the machine is ready for operation. The two foam components are continually pumped around a closed loop which begins at the bottom of the reservoir tank and ends at the reservoir. This recirculation step gets the material flowing smoothly throughout the system so there are few pressure variations within the system when foam is dispensed. The pressure within the lines is adjusted so it balances the pressure produced at the dispense ports.

Figure 2. Foam Processor Control Panel

When material is to be dispensed from the machine, the fluid is directed out of the dispense ports (Figure 5). Since the pressures are balanced, the material starts to flow immediately in the correct proportion. Once the material leaves the dispense ports, the dynamic mixer combines them into a homogeneous mixture.

Equipment Evaluation

To prove-in the machine for production use, both the shot-to-shot consistency and the mixing capacity had to be determined and quantified. Other physical properties of the foam were measured to ensure that the machine processed foam was compatible with existing material specifications.

Before accepting the equipment for purchase, Bendix required the manufacturer to perform an evaluation of shot-to-shot consistency and mixing capacity. Data provided by the manufacturer proves that the machine processes the foam within the ± 1 percent tolerance limit set forth in the equipment specification. Likewise, the cast samples exhibited an improved consistency in cell structure with no indication of dimensional instability when processed as required. On the basis of this information, Bendix agreed to purchase the equipment.

Figure 3. Foam Processor Dispense Head

As soon as it received the foam processor, Bendix initiated the activities necessary to develop a production process. These activities consisted of five areas which would determine the effects of machine processing on the foam's physical characteristics: machine consistency; mold preheat effects; foam exit temperature at the mixer; glass transition temperature; and density variations in the cured foam samples.

The machine consistency study (Tables 1 and 2) paralleled efforts at the manufacturer. The work was repeated to measure the effects of factory environment on machine performance. Since the equipment does not incorporate heating or cooling capabilities, the foam components are stored at room temperature. When the room temperature drops, the viscosity of the material increases, which increases the operating pressures of the machine. The

Figure 4. Recirculate Mode of Automated Equipment

Figure 5. Dispense Mode of Automated Equipment

Table 1. Shot-to-Shot Consistency
Calibration Run

Shot*	R	T	Ratio
Run 1**			
1	9.80	16.02	0.612
2	9.95	16.18	0.615
3	10.00	16.26	0.613
4	9.97	16.21	0.619
5	9.97	16.25	0.614
6	9.83	16.07	0.612
7	9.95	16.20	0.614
8	9.96	16.20	0.615
9	9.96	16.26	0.613
10	9.94	16.17	0.615
11	9.81	16.07	0.610
12	9.94	16.19	0.614
13	9.95	16.21	0.614
14	9.97	16.24	0.614
15	9.98	16.22	0.615
16	9.80	16.05	0.611
17	9.91	16.16	0.613
18	9.99	16.24	0.615
19	9.96	16.20	0.615
20	9.94	16.22	0.613
21	9.80	16.07	0.610
22	9.91	16.19	0.612
23	9.99	16.21	0.616
24	9.94	16.22	0.613
25	9.97	16.25	0.614
$\bar{x}$	9.928	16.182	0.614
σ	0.065	0.070	0.002
$\bar{x}-3\sigma$	9.733	15.972	0.608
$\bar{x}+3\sigma$	10.122	16.393	0.619
$\bar{x}-2\%$			0.602
$\bar{x}+2\%$			0.626

Table 1 Continued. Shot-to-Shot
Consistency
Calibration Run

Shot*	R	T	Ratio
Run 2**			
1	17.67	28.62	0.617
2	17.66	28.60	0.617
3	17.71	28.65	0.618
4	17.70	28.64	0.618
5	17.66	28.60	0.617
6	17.68	28.62	0.618
7	17.70	28.65	0.618
8	17.69	28.67	0.617
9	17.69	28.65	0.617
10	17.65	28.60	0.617
11	17.70	28.61	0.619
12	17.66	28.60	0.617
13	17.66	28.60	0.617
14	17.68	28.62	0.618
15	17.67	28.61	0.618
16	17.63	28.59	0.617
17	17.67	28.59	0.618
18	17.67	28.62	0.617
19	17.66	28.62	0.617
20	17.65	28.59	0.617
21	17.69	28.67	0.617
22	17.65	28.61	0.617
23	17.66	28.62	0.617
24	17.69	28.62	0.618
25	17.71	28.59	0.619
$\bar{x}$	17.674	28.618	0.617
σ	0.021	0.024	0.001
$\bar{x}-3\sigma$	17.611	28.546	0.616
$\bar{x}+3\sigma$	17.737	28.691	0.619
$\bar{x}-2\%$			0.605
$\bar{x}+2\%$			0.629

Table 1 Continued. Shot-to-Shot
Consistency
Calibration Run

Shot*	R	T	Ratio
Run 3**			
1	9.66	15.87	0.609
2	9.65	15.75	0.613
3	9.54	15.79	0.604
4	9.67	15.80	0.612
5	9.58	15.67	0.611
6	9.65	15.80	0.611
7	9.67	15.74	0.614
8	9.59	15.81	0.607
9	9.61	15.79	0.609
10	9.62	15.71	0.613
11	9.57	15.84	0.604
12	9.63	15.71	0.613
13	9.61	15.81	0.608
14	9.54	15.78	0.605
15	9.60	15.70	0.611
16	9.59	15.82	0.606
17	9.61	15.79	0.609
18	9.61	15.79	0.609
19	9.61	15.77	0.609
20	9.58	15.68	0.611
21	9.60	15.73	0.610
22	9.58	15.83	0.605
23	9.60	15.76	0.609
24	9.62	15.78	0.610
25	9.58	15.75	0.608
$\bar{x}$	9.607	15.891	0.609
σ	0.035	0.606	0.003
$\bar{x}-3\sigma$	9.502	14.702	0.601
$\bar{x}+3\sigma$	9.712	17.709	0.618
$\bar{x}-2\%$			0.597
$\bar{x}+2\%$			0.621

*5-second shot

**Units are grams

Table 2. Dispensed Material Shot Size Consistency

Sample	Dispensed Weight (Grams)	Sample	Dispensed Weight (Grams)
1	15.29	13	15.39
2	15.12	14	15.05
3	15.95	15	15.37
4	16.17	16	14.99
5	16.10	17	15.70
6	14.94	18	14.69
7	15.35	19	15.85
8	15.08	20	14.85
9	15.25	21	15.29
10	15.18	22	15.05
11	15.13	23	15.53
12	15.32	24	15.39
		25	15.07
<hr/>			
$\bar{x}$	= 15.324		
$\bar{x}+3\sigma$	= 16.503		
$\bar{x}-3\sigma$	= 14.225		
σ	= 0.380		

evaluation concluded that the effects of room temperature variations on the machine accuracy are negligible. However, the equipment should not be operated at a temperature below 21°C to avoid excessive operating pressures.

The data in Table 1 was taken from three calibration runs on three successive days. The average ratio (or $\bar{x}$) for each run has been computed along with the standard deviation (σ). The significance of this data lies in the fact that statistically the equipment shows well over a 99 percent confidence level for being within ratio tolerance. The shot-to-shot consistency also improves at larger throughput settings as can be seen by comparing the standard deviation of Run 2 (medium throughput setting) with both Run 1 and Run 3 (low throughput settings).

Table 2 data was taken to determine the range of dispensed weights of mixed foam for a particular machine setting. This information will be helpful for using the machine for casting product in molds without any venting. The data indicates that the consistency of the dispensed weight is in the ± 5 percent range.

The next portion of the investigation was intended to determine the effects of mold preheat temperature on the density of the machine processed foam. The results are shown in Figure 6. The decrease in density with respect to increasing mold preheat temperature is roughly exponential. This data is consistent with past experience with manual mixing procedures.

A major concern with machine processed foam was the foam exit temperature which could alter the physical properties of the foam material. The high shear dynamic mixer used on the equipment generates enough heat within the foam to raise its temperature well above ambient. Figures 7 and 8 show the foam exit temperature as a function of mixer speed, material throughput, and time. The trend is exponential with a maximum temperature reached at high mixer speeds with low throughput.

This information shows that the cream time of the material is reduced with increasing temperature. A reduced cream time gives the foam less time to work in the mold, thus reducing its filling capacity. In addition, samples cast at the higher mixing speed exhibited slight streaking in the direction of foam rise when sectioned. The lower mixing speeds gave uniform consistency in the cross-sectioned material. Even though the streaking was not considered detrimental to material characteristics, the slower speed mixing is preferable from a visual inspection viewpoint.

Figures 9 and 10 provide a comparison of samples cast by the machine, manually in the laboratory, and by hand in the production department. The larger bubbles within the foam represent an inconsistency in the mixing process and are not characteristic of the foam itself. The foam processor does not introduce air into the mix so there is much more consistency in the cross-section of the casting.

The physical properties of these samples (Table 3) show the differences between the processes. The apparent 10 percent differential between the hand prepared samples cast in the laboratory and the foam encapsulation system is mainly the result of a more homogeneous mixture provided by the machine. The efficiency of the dynamic mixer is much greater than the mixing action provided by hand. The production area sample shows a better correlation with the machine because of a better mixing process than in the laboratory. However, the production equipment is still not as thorough as the foam processor and there is a slight change in the material characteristics between the fast and slow mixer speeds on the foam processor. This difference is attributed to a more complete mixing action of the slower speed mixer. For this reason the slower mixer speed is recommended for production use.

Figure 6. Specimen Density Versus Mold Preheat Temperature for 2170288 (128 kg/m³ Density) Foam

The data in Table 3 also includes the glass transition temperature (T_g) for each sample. The T_g is consistent for all samples since all were processed similarly. Each sample had the same preheat temperature and cure temperature. A marked change in T_g may be seen in the data presented in Figure 11. The information here was derived from the samples cast during the mold preheat experiment and shows an exponential rise in T_g with a rise in mold preheat temperature. The curve appears to be asymptotic to 136°C which would be consistent with previous data.

If the data presented in Figures 11 and 6 are combined, a correlation may be seen between the mold preheat temperature, glass transition temperature and specimen density. The data shows that

Figure 7. Mixed Foam Time Versus Temperature at 4300 rpm

the density and glass transition temperature may be varied over a wide range by changing the mold preheat temperature. From an application standpoint, the higher glass transition temperature and lower density are desirable. This being the case, a recommendation may be made to limit the mold preheat temperature to a lower limit of 54°C. This would yield material with a glass transition temperature much higher than required to assure no change in the material size or physical characteristics. Likewise, the density of the specimen is within an acceptable range for encapsulating most products. Increasing the temperature will lower the density and raise the glass transition temperature--which will improve the foam characteristics.

The data presented here is representative of small amounts of mixed foam. The sample size used to generate the data is approximately 125 grams. As the sample size gets larger, the effect of processing parameters such as mold preheat temperature or cure cycle becomes less pronounced and the shapes of the curves will

Figure 8. Mixed Foam Time Versus Temperature at 6900 rpm

change to reflect the change in exotherm temperatures. This data, however, is applicable to most electronic products manufactured at Bendix and should serve as a guide in new applications.

Processing Considerations

The scope of this process development order included not only an investigation of the effects of machine processing on material characteristics but also development of guidelines to properly use this equipment. An interpretation of the data with specific emphasis on application is presented here.

The machine must be calibrated each time the equipment is started up. Calibration consists of catching the stream of material in separate pre-weighed cups as it exists from the dispense head for a predetermined length of time. The ratio of the dispensed weight must be between 0.607 and 0.619. This will assure that

FOAM PROCESSOR SAMPLE 1A

MATERIALS LABORATORY SAMPLE

Figure 9. Foam Processor Versus Materials Laboratory Samples

the proper amount of each component is being used. The consistency data from Table 1, and operating experience, show that once the ratio is set, the machine will hold it for several hours while recirculating. As a practical rule of thumb, if the machine is calibrated at the start of the shift the calibration should be checked after lunch and adjusted as necessary.

The machine is put in the dispense mode to encapsulate product. This mode consists of metering the calibrated material stream into the mixer and allowing the foam to exit from the machine into a preheated mold.

The foam processing equipment operates on a continuous flow principle (manual procedures are batch processes). The pumps in the machine will deliver continuous streams of material in the proper ratio with a delivery rate measured in grams per second. A little arithmetic is required to determine the amount of foam required to encapsulate a given product. For example, for a part requiring 125 grams of foam it is necessary to

FOAM PROCESSOR SAMPLE 1C

PRODUCTION SAMPLE

Figure 10. Foam Processor Versus Production Samples

- Determine throughput in grams/second,
- Divide the total amount required by the throughput, and
- Set the dispense timer to the above answer.

In Table 1, Shot 1, of Run 1, it can be seen that the machine was delivering 9.8 grams of R and 16.02 grams of T in one 5-second shot. This translates into

$$\frac{(9.8 + 16.02)\text{g}}{5\text{s}} = 5.16 \text{ g/s},$$

or, for 125 grams,

$$\frac{125 \text{ g}}{5.16 \text{ g/s}} = 24.22 \text{ s}.$$

Table 3. Physical Properties of Selected Foam Samples

Sample*	Ultimate Strength (MPa) (psi)		Modulus (MPa) (psi)		Density (kg/m ³) (lb/ft ³)		T _g (°C)
Material Laboratory Sample (6-18-76)							
1-1	2.48	(360)	28.7	(4167)	155.8	(9.73)	144
1-2	2.46	(357)	27.8	(4032)	155.5	(9.71)	
1-3	2.52	(365)	30.8	(4464)	156.3	(9.76)	
1-4	2.49	(362)	30.8	(4464)	156.8	(9.79)	
1-5	2.53	(367)	29.7	(4310)	157.1	(9.81)	
1-6	2.42	(351)	29.7	(4310)	155.4	(9.70)	
Foam Processor Second Sample, Fast Mix (6-22-76)							
1A-1	2.65	(385)	33.1	(4807)	170.7	(10.66)	144
1A-2	2.79	(405)	33.1	(4807)	172.5	(10.77)	
1A-3	2.79	(405)	33.1	(4807)	170.6	(10.65)	
1A-4	2.93	(425)	34.5	(5000)	173.3	(10.82)	
1A-5	2.93	(425)	35.9	(5210)	174.1	(10.87)	
1A-6	2.93	(405)	35.9	(5000)	172.2	(10.75)	
Foam Processor Third Sample, Slow Mix (6-29-76)							
1C-1	3.05	(442)	35.9	(5210)	174.3	(10.88)	141
1C-2	3.05	(425)	35.9	(5210)	170.7	(10.66)	
1C-3	2.99	(435)	37.4	(5430)	171.9	(10.73)	
1C-4	3.02	(438)	37.4	(5210)	174.1	(10.87)	
1C-5	3.16	(458)	39.2	(5680)	175.7	(10.97)	
1C-6	3.15	(457)	39.2	(5430)	176.2	(11.00)	

Table 3 Continued. Physical Properties of Selected Foam Samples

Sample*	Ultimate Strength (MPa) (psi)		Modulus (MPa) (psi)		Density (kg/m ³) (lb/ft ³)		T _g (°C)
Production Sample (6-30-76)							
1D-1	3.06	(444)	39.2	(5430)	168.8	(10.54)	142
1D-2	3.04	(441)	39.2	(5680)	169.6	(10.59)	
1D-3	2.61	(378)	31.9	(4630)	165.6	(10.34)	
1D-4	2.99	(435)	31.9	(5680)	169.1	(10.56)	
1D-5	2.56	(372)	33.1	(4807)	160.6	(10.03)	
1D-6	2.55	(370)	33.1	(4807)	163.2	(10.19)	

*Samples were taken from center of 203 by 203 by 82.5 mm block, 49°C preheat, 30 minutes at room temperature, and 107°C cure for four hours.

Figure 11. Glass Transition Temperature Versus Mold Preheat Temperature for 2170288 (128 kg/m³ Density) Foam

Setting the dispense timer for 24.22 s will deliver the desired 125 g of material into the mold.

The third portion of the cycle is purging the system. Since there is combined material in the mixer and mixing chamber, methylene chloride solvent must be run through the mixer to remove this material. This operation is simple and is performed automatically if desired. Once cleaned, the system is again ready for use. In this case, the calibration of the machine is unaffected by the purging of the mixer.

The set-up and calibration of the equipment is covered by General Process Instruction P-0860045 and a material processing specification. Specific product requirements such as amount of foam required and mold preheat will be contained in the production traveler.

ACCOMPLISHMENTS

An analysis of the data gathered during this endeavor shows that the foam processor will supply material with better consistency than current manual procedures. The physical properties of the cured material are roughly the same since the machine does not affect the fundamental determinants of density and glass transition temperature. These properties are determined by mold preheat, and the quantity of foam material. Vent hole size also affects these properties but this parameter was not investigated.

The operation of the equipment has been defined and will be outlined in a material processing specification covering automated foam processing. Analysis of the machine operation by methods engineers shows that approximately 80 percent of the time involved in mixing and pouring potting material into a unit by manual procedures may be saved, along with approximately 50 percent of the material involved.

FUTURE WORK

The procedures developed during this effort will now be tested and refined in a production environment. Since the groundwork has been laid for production use, a second machine has been ordered for use in the fireset manufacturing facility with the purchase of other systems being considered.

Appendix
CONDENSED VENDOR DATA

Specification Number	Throughput Setting	Shot Size (Grams)	Percent High	Percent Low
T-Component				
2170287	Lo	19.146	0.280	0.340
	High	90.147	0.210	0.270
2170288	Lo	19.187	0.432	0.401
	Medium	31.418	0.388	0.280
	High	76.415	0.160	0.250
2170289	Lo	18.501	0.540	0.280
	High	91.326	0.160	0.240
2170290	Lo	15.851	0.561	0.763
	Medium	26.648	0.457	0.368
	High	45.671	0.300	0.190
R-Component				
2170287	Lo	13.010	0.910	0.620
	High	61.383	0.270	0.200
2170288	Lo	11.785	0.636	0.721
	Medium	18.960	0.940	0.730
	High	46.739	0.470	0.480
2170289	Lo	11.803	0.822	0.872
	High	58.450	0.250	0.420
2170290	Lo	10.592	0.642	0.869
	Medium	17.727	0.524	0.377
	High	29.320	0.570	0.400
Ratio				
2170287	Lo	0.680	0.975	0.566
	High	0.681	0.200	0.190
2170288	Lo	0.614	0.580	0.896
	Medium	0.604	0.847	0.588
	High	0.612	0.289	0.298
2170289	Lo	0.633	0.730	0.710
	High	0.639	0.500	0.200

Specification Number	Throughput Setting	Shot Size (Grams)	Percent High	Percent Low
Ratio				
2170290	Lo	0.668	0.593	0.859
	Medium	0.665	0.518	0.497
	High	0.642	0.426	0.367
Specification limits allow ± 1 percent accuracy by weight				

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ELECTRICAL: Foam Encapsulation

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