Study of adhesive line quality and capacitance parameter in shaft/bush joints

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Abstract. This article contains the analysis of application of adhesive joints and peculiarities of the control carried out for these joints. Requirements to a control unit, which shall be built into a conveyer line, are described. Besides, a new technique of shaft/bush joints is analyzed; a new control method is tested based on this technique. Obtained results allow making conclusions regarding the applicability of this method and its purposefulness.

1. Introduction
The adhesive joints become more and more expanded due to the creation of quality synthetic glues. In the machinery manufacturing, adhesive joints for combining various materials are use; these joints behave perfectly under normal and elevated temperatures. The glues allow increasing of constructional strength, reducing of product weight, etc. In the machinery manufacturing, the glues are applied, which can be used for strength joints under service temperatures up to 250-350°C, and some glue compositions can be used in structures shortly impacted by temperatures up to 1000°C and higher. In the machine tool building, the synthetic glues are used for the adhesion of plastic built-up guideways with cast-iron bed bases, rubber with metal, during gluing of cutting tools made of hard alloys and ceramic materials with metal mandrels and for other joints, requiring high strength properties. The glues used during production tooling assembling allows reaching of the required strength, simplifying of designs, reducing of the structure weight, lowering of its price 1.5-2 fold as well as reducing of labor required for its processing and assembling.

The control of adhesive joint assembling is one of mandatory steps of the assembling process. Control methods and organizational forms depend on the joint criticality, product dimensions, as well as manufacturer’s equipment and production volumes.

For the adhesion of non-critical joints, the quality control is carried out by means of visual inspection. For the selection of an adhesive joint control methods, an important criterion is the production volume. For small series and single products, universal control methods are used, which do not require high qualifications and expensive preparation. Nondestructive testing is mostly used. In this case, strongly critical products are exclusions. For large series and mass production these limitations are not available. However, up to the present moment, manufacturers have a problem with choosing a control
unit, which can be easily integrated into a production line. Destructive control units cannot be mounted on conveyor lines.

The following requirements are set to control units, which are integrated into conveyor lines for the quality control of adhesive joints. The unit operation method shall be safe for personnel, do not require unhandy protection facilities and integrate easily into the automatic cycle. The unit shall be compact and easily adjustable for new products without involving any qualified personnel. This unit shall not require long preparation and final periods for its adjustment for a new product series with different dimensions, width and shape, as well as chemical properties of adhesive joints. The main requirement to the integrated units caused by peculiarities of the conveyor lines is the fulfillment of control operations within an assembling cycle. As we can see from the above, control methods do not mostly allow creating of a unit, which can be used for the automated control within conveyor lines [1].

2. Samples of the hypothesis

Due to this fact, a task has been set to develop a control procedure for adhesive joints, which involves electric resistance and electric capacitance methods. This approach is based on the use of precision electric resistance and electric capacitance measuring methods for the quality control of adhesive joints [2].

A new assembling technique for cylindrical adhesive joints is currently developed at the N. E. Bauman Moscow State Technical University. The main task, which arises during an experiment involving the process line formation, is the control of hand curing times upon different roller temperatures. The literature analysis discovered an interrelation between an adhesive compound cure degree and its dielectric conductivity [3]. This interrelation allows control of the hand curing time based on a value of the polymer dielectric conductivity. For the control, a dielectric conductivity value shall be determined, which corresponds to a time of attainment of the hand strength.

To control the time of hand cure during the study, we shall determine the dependence of a capacitance value on adhesive line parameters; besides, the glue dielectric conductivity shall be determined [4].

The open cylindrical adhesive joint can be presented as a cylindrical capacitor. To calculate the capacitance of the cylindrical capacitor, the following formula is used:

\[
C = \frac{2\pi \ast l \ast \varepsilon \ast \varepsilon_0}{\ln \left( \frac{r_1}{r_2} \right)}
\]

where \( l \) – capacitor length, mm;
\( \varepsilon \) – dielectric conductivity of adhesive layer;
\( \varepsilon_0 \) – dielectric conductivity of vacuum;
\( r_1 \) – inner cylinder radius, mm;
\( r_2 \) – outer cylinder radius, mm.

3. Research results

As of the moment, first experiments were carried out, during which the dielectric conductivity of a cylindrical adhesive joint with a process line made without roller heating were controlled after complete glue curing. A diameter clearance in the joint was 0.3 mm; the Loctite 638 anaerobic adhesive was used. The joint diameter is 36 mm, the joint length is 31 mm, the adhesive was applied on a 10 mm line.

The purpose of the first phase of the experiment was to determine the capacitance value. For this, 26 points were conditionally chosen on an investigated sample (Figure 1).
To get more data, 10 measurements were carried out at each point. The obtained data are presented in Table 1.

| Measurement number | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   |
|--------------------|------|------|------|------|------|------|------|------|------|------|
| 1                  | 9.66 | 11.67| 3.08 | 6.59 | 4.56 | 7.05 | 6.79 | 6.33 | 6.28 | 6.58 |
| 2                  | 7.23 | 4.34 | 1.76 | 2.13 | 8.40 | 5.13 | 4.32 | 10.48| 5.28 | 8.93 |
| 3                  | 4.54 | 6.38 | 5.77 | 4.01 | 6.97 | 5.65 | 5.87 | 4.51 | 3.61 | 4.51 |
| 4                  | 1.16 | 5.50 | 8.18 | 3.05 | 6.09 | 4.57 | 7.21 | 9.96 | 6.24 | 2.47 |
| 5                  | 2.45 | 2.93 | 7.40 | 2.96 | 7.39 | 4.14 | 4.65 | 3.61 | 1.57 | 3.33 |
| 6                  | 1.03 | 6.50 | 6.01 | 2.61 | 5.64 | 3.99 | 1.70 | 2.03 | 2.91 | 2.18 |
| 7                  | 5.56 | 4.12 | 1.07 | 2.08 | 1.53 | 1.47 | 5.21 | 12.29| 3.11 | 3.28 |
| 8                  | 4.24 | 2.33 | 4.80 | 5.14 | 7.02 | 9.60 | 10.44| 3.43 | 2.52 | 7.87 |
| 9                  | 5.16 | 6.51 | 6.41 | 2.70 | 10.06| 2.82 | 2.74 | 3.22 | 3.00 | 1.96 |
| 10                 | 8.75 | 12.28| 7.21 | 1.75 | 2.86 | 4.36 | 9.04 | 7.28 | 4.64 | 6.95 |
| 11                 | 7.61 | 2.11 | 4.70 | 5.79 | 3.11 | 5.84 | 3.48 | 6.38 | 3.94 | 7.92 |
| 12                 | 5.49 | 2.58 | 9.63 | 4.85 | 10.31| 6.18 | 8.31 | 4.53 | 6.14 | 4.72 |
| 13                 | 8.81 | 3.14 | 3.46 | 11.68| 5.27 | 5.00 | 4.01 | 3.92 | 4.43 | 7.64 |
| 14                 | 6.70 | 3.37 | 1.71 | 6.80 | 7.95 | 4.05 | 3.31 | 8.76 | 3.11 | 3.61 |
| 15                 | 1.59 | 3.43 | 1.55 | 3.23 | 2.97 | 12.15| 6.01 | 7.60 | 5.29 | 2.92 |
| 16                 | 4.99 | 12.24| 11.00| 4.18 | 4.18 | 10.87| 2.63 | 5.80 | 3.27 | 10.00|
| 17                 | 6.11 | 2.31 | 14.61| 8.00 | 6.01 | 7.73 | 3.77 | 4.42 | 5.23 | 9.61 |
| 18                 | 4.51 | 1.80 | 1.58 | 1.10 | 9.47 | 1.94 | 1.75 | 10.18| 4.46 | 7.14 |
| 19                 | 7.98 | 8.95 | 5.13 | 10.66| 5.21 | 6.32 | 4.96 | 4.28 | 2.11 | 8.35 |
| 20                 | 7.20 | 3.66 | 10.01| 3.95 | 7.55 | 1.60 | 5.29 | 5.50 | 9.76 | 5.19 |
| 21                 | 2.38 | 3.68 | 3.63 | 4.12 | 9.42 | 4.00 | 9.62 | 1.53 | 5.21 | 1.69 |
| 22                 | 10.66| 3.99 | 9.85 | 5.75 | 6.09 | 7.34 | 2.37 | 8.09 | 6.13 | 4.16 |
| 23                 | 2.50 | 4.11 | 1.73 | 1.01 | 3.98 | 5.25 | 4.62 | 4.61 | 9.22 | 8.34 |
| 24                 | 1.37 | 2.65 | 5.59 | 9.44 | 4.70 | 6.25 | 7.80 | 2.97 | 6.97 | 4.65 |
| 25                 | 2.01 | 1.56 | 6.61 | 4.52 | 8.63 | 3.90 | 4.04 | 2.54 | 7.64 | 5.47 |
| 26                 | 8.55 | 2.81 | 6.00 | 1.09 | 5.39 | 3.44 | 1.88 | 3.87 | 5.57 | 3.65 |

Table 1. Definition the capacity value of preproduction model (nF)

Based on the obtained data, a plot was developed (Figure 2).
During the study, the following result was obtained: the average sample capacitance value is 5.357 nF. The plot shows that the peak capacitance value is in a point, where the contact area of glued surfaces was larger. Besides, based on minimum values, a conclusion can be made on the insufficient width of the adhesive line.

In addition to developing a control method at BMSTU a study was conducted on the effect of roughness on the control and strength of adhesive joints. The obtained data and calculations showed that an increase in internal stresses with the change in roughness is almost linear [5].

4. Conclusion
According to the measurement results, the following was established: the standard deviation of the obtained results was 0.175 pF, the average value of the capacitance was 26.38 pF, and the thickness was 1.85 mm. An assessment of the area showed that the measured value = 1.408 × 10⁻³ m², and the calculated 1.40 × 10⁻³ m². The relative measurement error did not exceed the value of 0.56% [1, 6]. The relative error in measuring the contact area is not more than 0.6%, which is an order of magnitude more accurate than the existing non-destructive testing means built into automated lines. This measurement error ensures measurement accuracy glue joint defect within ± (5 ... 10) mm².

Based on the obtained data we can make a conclusion that the dependence of capacitance on a contact area of adhesive joint of cylindrical details is available. In its turn, this allows proceeding to a second study phase, i. e. to the determination of dielectric conductivity of an anaerobic adhesive based on the capacitance value obtained for this joint.

Advantages of the method:
- high accuracy of measurements;
- safe for the health of workers, do not require bulky protective equipment;
- compactness, the possibility of unification and quick readjustment;
- setup does not require highly qualified personnel.
- simple measurement scheme;
The disadvantages of the method:
- high measurement accuracy places high demands on accuracy instrument measurements.

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