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## **MODEL OF THE TECHNOLOGICAL PROCESS OF WEDGE BONDING BASED ON FEK DELVOTEC 6400 IN THE PRODUCTION OF HYBRID ELECTRONIC MODULES**

Modern development of microelectronics and hybrid electronic modules is characterized by continuously increasing requirements for the accuracy, reliability, and stability of interconnections in the manufacturing process of electronic components. One of the most widely used technologies for forming electrical contacts is thin aluminum wire wedge bonding, which ensures high connection quality and the possibility of manufacturing process automation [1,2]. The use of the FEK Delvotec 6400 system makes it possible to achieve high-precision tool positioning, control of technological parameters, and stability of the bonding process in the production of hybrid electronic modules. In this regard, an important task is the development of a model of the wedge bonding technological process, which will allow analyzing the influence of equipment operating modes on the quality of interconnections and improving the efficiency of the manufacturing process [3,4].

The model of the technological process phases within the working area is required to describe the sequence of wedge bonding operations inside the рабочая зона. It allows the Digital Twin to determine the current stage of the bonding tool operation: approach, touch-down, first bond, loop formation, second bond, or wire tear-off, and can be represented as follows:

$$\begin{aligned} \phi_i(t) &\in \{A_1, TD_1, B_1, L, A_2, TD_2, B_2, Tear, End\} \\ \Phi_i: A_1 &\rightarrow TD_1 \rightarrow B_1 \rightarrow L \rightarrow A_2 \rightarrow TD_2 \rightarrow B_2 \rightarrow Tear \rightarrow End \end{aligned} \quad (1)$$

*Де:*  $\phi_i(t)$  - current process phase for the  $i$ -th wire;  $A_1$  - approach to the first bonding point;  $TD_1$  - touch-down at the first bonding point;  $L$  - wire loop formation;  $A_2$  - approach to the second bonding point;  $TD_2$  - touch-down at the second bonding point;  $B_2$  - formation of the second bonded contact;  $Tear$  - wire tear-off after the second bond;  $End$  - completion of one wire bonding cycle.

Approach to the first bonding point ( $A_1$ ) – At this phase, the bonding tool moves toward the coordinates of the first bonding pad according to the specified trajectory and positioning system parameters. The main objective of this stage is to ensure accurate tool alignment with the contact area without causing mechanical damage to the surface.

Touch-down at the first bonding point ( $TD_1$ ) – At the moment the bonding tool contacts the surface of the first bonding pad, an initial mechanical force is applied and ultrasonic vibrations are activated. This phase ensures stable contact between the wire and the surface before the formation of the first bonded connection.

Formation of the first bonded contact ( $B_1$ ) – At this stage, plastic deformation of the aluminum wire and destruction of the oxide layer occur under the influence of ultrasonic energy. As a result, a metallic bond is formed between the wire and the bonding pad at the molecular level.

Wire loop formation ( $L$ ) – After the creation of the first bond, the bonding tool moves toward the second bonding point while simultaneously forming a wire loop of the specified geometry. The geometric parameters of the loop affect the mechanical stability of the interconnection and its operational reliability.

Approach to the second bonding point ( $A_2$ ) – During this phase, the bonding tool performs precise movement toward the second bonding pad according to the predefined trajectory. The positioning system controls the tool coordinates to ensure the accuracy of the second bonded connection.

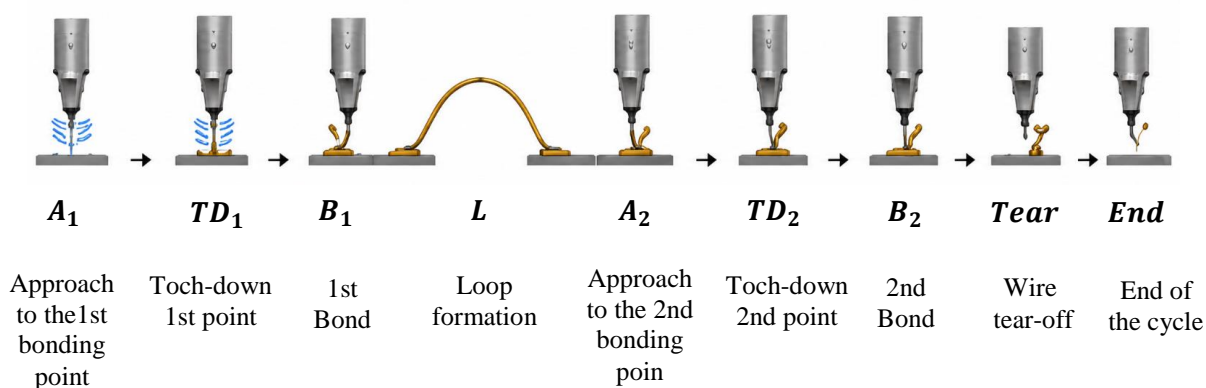
Touch-down at the second bonding point ( $TD_2$ ) – At the moment the tool contacts the second bonding pad, mechanical force is applied and the wire position in the bonding area is stabilized. This phase serves as a preparatory stage before the formation of the second bond.

Formation of the second bonded contact ( $B_2$ ) – At this stage, the second bonded connection is formed through the application of ultrasonic vibrations and mechanical pressure. As a result, an electrical and mechanical connection between the bonding pads is established through the aluminum wire.

Wire tear-off after the second bond (*Tear*) – After the completion of the second bonded contact, controlled separation of the wire from the bonding tool is performed. This operation completes the interconnection formation process and prepares the system for the next bonding cycle.

Completion of one wire bonding cycle (*End*) – At the final stage, the system performs verification of the technological process state and switches to preparation mode for the next wire bond. All process parameters can be stored in the Digital Twin for further analysis and quality monitoring.

For a better understanding of the technological process phase model, their sequence is presented in the form of a graphical representation with explanations in Figure 1.



**Fig. 1 Graphical representation of the sequence of wedge bonding technological process phases**

**Conclusion.** Based on the conducted analysis of the wedge bonding technological process, it was determined that the use of the FEK Delvotec 6400 system ensures high precision in the formation of interconnections and stability of bonding parameters in the production of hybrid electronic modules. The developed model of the technological process phases makes it possible to formalize the sequence of wire bonding operations and provides the possibility of integrating the obtained data into the Digital Twin structure for further monitoring and analysis of the manufacturing process state. It was established that the quality of bonded contacts largely depends on the stability of ultrasonic operating modes, the positioning accuracy of the bonding tool, and the control of wire loop formation parameters [5-8]. The obtained results create a foundation for the further development of intelligent digital manufacturing systems, adaptive control, and defect prediction in microelectronics.

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