Obtaining permanent connections by electromagnetic method

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Abstract. The article deals with the technological processes of magnetic pulse crimping for the production of non-removable metal, metal-glass and metal-ceramic units. The analysis of connection of stranded wires with tips of onboard cable networks of aviation and space equipment. Assembly of metal-glass fuses and metal-ceramic knots of electrovacuum devices is carried out. The use of uniform remote electromagnetic influence on the assembled units allows for more dense packing of conductive conductors in the contacts, eliminate soldering and provide heat dissipation in the insulation units of ultrahigh frequency devices.

1. Introduction

In the production of electronic equipment, aircraft and spacecraft for composite compounds, magnetic pulse processing, which is characterized by a remote uniform and strictly dosed effect on the interface zone, is becoming increasingly common [1,2].

The most widespread are the Assembly processes using electromagnetic pressure according to the «crimper» scheme of axisymmetric composite connections of stranded cables, metal-glass and metal-ceramic assemblies [3,4].

2. Magnetic pulse crimping of stranded cables

The principle of magnetic pulse crimping pliers for sealing electric wires in the terminals or the capacity of multicore cables is as follows, see Figure 1.

The tip 3 is installed in the inductor (working tool) 2 which is connected to the pulse current generator 1. When passing through the cylindrical inductor 2 current pulse Id there is an alternating magnetic flux H, which provides the tip of the induced current flow Ii. The interaction of the induced current with the primary magnetic flux leads to the appearance of radially acting ponderomotor forces-electromagnetic pressure Pm, due to which the deformation of the tip and compaction of the internal volume of the tip is carried out. Power consumption of the equipment – 10 kJ, natural frequency of discharge current 20 kHz, amplitude value of discharge current up to 200 kA.

When the discharge of the GPC on the coils of the inductor, a current pulse flows, the magnetic field of which induces induced currents in the pusher. The interaction of induced currents in the pusher with the magnetic field of the inductor leads to the appearance of ponderomotor forces – a pulse of magnetic pressure.
Figure 1. Schematic diagram of electromagnetic crimping for sealing electrical wires in the tips
1 – pulse current generator (GPC); 2 – inductor; 3 – tip; 4 – stranded wire; \(I_d\) – discharge current; \(H\) – magnetic flux; \(I_i\) – induced current; \(P_m\) – electro-magnetic pressure.

In contrast to the currently existing cold crimping with a special tool that creates wire contact at several points, magnetic pulse crimping provides uniform crimping and contact over the entire interface surface between the tip and the live conductors.

The use of uniform remote electromagnetic action provides a more dense packing of conductive conductors in the contacts, which allows you to enter an additional number of conductive conductors into the contacts, increasing the cross-sectional area, reducing the transient resistance, reducing losses on ohmic heating, increasing the strength of the connection, ultimately reducing the weight and increasing the reliability of on-board cable networks [3-5].

The authors conducted a study of the process of high-speed deformation of the tip material and its introduction into conductive veins. The dependences of the mechanical strength and transient resistance of the connection on the input energy of the copper tip with copper and aluminum wires are obtained, Figure 2.

Figure 2. Dependence of mechanical strength (a) and transient resistance (b) on the pulse energy \(W\).

Compression technology contacts and splice wires and cables by the method of magnetic-pulse processing of materials can be used not only in the manufacture of onboard cable network, but in other industries, particularly in the power sector in the creation and repair of power networks (cable and overhead lines), for any purpose, instrumentation, aviation, automotive and machine building enterprises of the defense complex, agriculture, etc.
3. Multi-pass magnetic pulse crimping of metal-glass and metal-ceramic units

In the production of products in electronic technology, instrument-making there is a need to combine heterogeneous materials, such as metal-ceramics, metal – glass.

The use of traditional methods of Assembly of multi-element compounds is ineffective and leads to irrationally high costs of materials and energy. The mechanical effect leads to the emergence of cracks or complete fracture of glass or ceramic. These disadvantages are eliminated by the use of Assembly using the energy of the electromagnetic field. It is proposed to use magnetic pulse processing.

In the process of magnetic pulse Assembly, the parts from the stack and ceramics are combined with the metal into a mechanically strong one-piece unit by plastic deformation of the enveloping conductive shell. However, intensive single-pass exposure with a high rate of deformation in this case is unacceptable. Magnetic pulse Assembly of metal-glass units (MGU) must be carried out by a series of pulses of low discharge energy (100-200 J). During the sampling of the gap between the shell and the glass frame due to induced currents, the metal is deformed and simultaneously heated. After cooling, tension is carried out in the connection without destroying the fragile base.

An example of the Assembly of a metal-glass fuse Assembly is shown in Figure 3.

Figure 3. Magnetic pulse crimping of metal-glass fuse.

1 – glass frame (tube); 2 – fusible element; 3 – tip; \( P_m \) – electromagnetic pressure.

Figure 4 shows a composite metal-ceramic film resistor pressed by electromagnetic forces. Here is also used in the Assembly of the multiple electromagnetic loading.

Figure 4. Scheme of electromagnetic crimping of film resistor

1 – frame; 2 – tip; \( P_m \) – electromagnetic pressure.

Composite multi-element metal-ceramic unit (MCU), shown in Figure 5, is a housing and insulation element of the microwave (SHF) electric vacuum device, which ensures the performance of structures at operating voltages of more than 10 kV and intense thermal loads.

When processing MCU mechanical methods, crimping Cams or rolling rollers in beryllium ceramics occurs foci of stress concentration, which lead to the destruction of ceramic parts, which is unacceptable in the production of microwave vacuum devices such as traveling wave lamps.
It is proposed for the Assembly of multi-element MCU to use a non-contact method of processing with a strict dosage of pressure by a pulsed magnetic field. In most cases, as previously mentioned, the process is not realized in one transition, since when the necessary configuration of the metal shell is reached in the ceramic rods, microcracks are formed as a result of intensive loading.

The conditions for qualitative crimping of metal shells on ceramic bases are formulated in [6] as follows:

\[ u_f > [u]; \quad v_c \leq [v]; \quad s \geq [s]; \quad J_m \leq [J_{m,max}] \]  

These terms are controversial, as it is necessary to carry out the final significant movement of the model \( u_f \) excess of set \([u]\) with restrictions \([v]\) impact velocity \( v_c \) shell with ceramics, the limitations of the momentum of the first half-wave magnetic pressure \([J_{m,max}]\) and the allowable minimum thickness of the shell \([s]\).

The critical values of collision velocities and magnetic pressure are established empirically. For different ceramic materials, their values are in the ranges: \( v = 0.5 - 3 \text{ m/s}, \quad J_m = (0.1 - 2) \times 10^4 \text{ N} \cdot \text{s/m}^2 \).

It is established that the conditions (1) can be realized only by multi-transient processing-multiple loading with a change (increase) of the load-the magnetic pressure pulse.

The theoretical analysis of the MCU crimping process was carried out by numerical simulation on a computer of a multi-transient magnetic pulse effect by repeatedly solving a single-transient problem using the equilibrium state of the system obtained from the previous solution as the initial state.

Figure 6 shows the design scheme, the configuration of the structure and the nature of the distribution of magnetic pressure at different stages of the process of crimping MCU, photos of typical products in Figure 7.
Figure 7. Typical MCU products made by magnetic pulse crimping.

Theoretical analysis and experimental studies using high-speed photoregistration of the MCU crimping process showed that the intensity of shaping in each loading pulse practically stops after the end of the first half-life of the load, which determines the role of the pulse of the first half-wave of magnetic pressure in shaping.

The analysis of loading conditions confirmed the assumption that the processing should be carried out in a series of pulses, increasing the deflection of the shell, taking into account that from transition to transition the equivalent inductance of the inductor-workpiece system increases, the magnetic pressure in the deformation zone decreases, and the deformation resistance as a result of hardening (hardening) increases. As a result, it is necessary to increase the discharge energy of the capacitive storage unit from transition to transition [6-9].

The remoteness of the impact, strict dosage of energy and the implementation of multiple loading are also needed in the implementation of the processes of calibration of metal elements (cuffs) of vacuum-tight MCU and straightening the bases of magnetic disks. The conditions of high-quality processing and technical requirements for special technological equipment (STE) are similar to those defined for the processing of composite MCU [9].

Comparison of theoretical studies of electromagnetic and power characteristics of magnetic pulse processing (MPP), data of high-speed photoregistration of pulse forming with data of measurement results and tests of the received details and knots allowed to define areas of effective variation of the parameters influencing quality of processing: working frequency of a discharge current \(f_d=3\text{÷}70\text{ kHz}\); pulse energy \(W=10\text{ kJ}\); working voltage \(U_w=0,5\text{÷}15\text{ kV}\) number of pulses in automatic mode \(N_t=1\text{÷}10\).

These data can be the source for the development of technical requirements for industrial equipment MPP [10-11].

4. Conclusion
To obtain composite integral axisymmetric compositions - metal, metal-glass and metal-ceramic units, magnetic pulse processing is expedient. It is possible to connect stranded wires with tips and splicing of onboard cable networks of aviation and space technology, assembly of metal-glass fuses and metal-ceramic units of electro-vacuum devices.

The use of uniform remote electromagnetic influence on the assembled units allows for more dense packing of conductive conductors in the contacts, eliminate soldering and provide heat dissipation in the insulation units of ultrahigh frequency devices.

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