Magnetic-pulse of assembly of details one-piece compositions

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Abstract. The article discusses the technological processes of magnetic-pulse assembly for obtaining one-piece metal, metal-glass and cermet units. The analysis of connection of stranded wires with lugs of on-board cable networks of aviation and space technology, assembly of metal-glass fuses and sintered assemblies of electrovacuum devices is carried out. The use of a uniform, radially remote electromagnetic effect on the assemblies to be assembled makes it possible to carry out a denser assembly of conductive conductors with lugs, to refuse soldering and to provide heat removal in the insulating assemblies of microwave devices.

1. Introduction
In the manufacture of electronic products, aircraft construction and the creation of spacecraft for obtaining composite compounds, magnetic-pulse processing is becoming increasingly widespread, which is characterized by a remote uniform and strictly dosed effect on the interface of the compounds [1, 2, 3].

An analytical review of scientific and technical literature has shown that the most widespread are assembly processes using electromagnetic pressure according to the «crimp» scheme of axisymmetric composite joints of multicore cables, metal-glass and cermet assemblies [4, 5].

The main problems in the preparation of such joints are different thermophysical properties of the joints, the difference in thickness, which affects different heat removal, the tendency of the joints to crack formation of fragile ceramic or glass assemblies [6, 7].

An analytical review of the production of permanent metal joints revealed the use of soldering or mechanical reduction technology. Soldering is characterized by hazardous production conditions and high labor intensity. With the mechanical compression of live conductors with a tip, the physical is obtained not over the entire interface area, but only at individual points. Also, during the operation of assembly joints of aluminum with copper, the effect of a galvanic pair occurs, which leads to corrosion of the joint, a change in the transition resistance in general [8, 9].

2. Magnetic-pulse crimping (MPC) of multicore cables
To reduce the effect of the galvanic pair during the further operation of the connection, the copper lug and aluminum cables are made tinned.

The essence of the MPC process is conventionally divided into 3 stages [10]. At the first stage, the assembly is carried out: into a tinned copper tip pos. 1 install a stranded aluminum cable pos. 2, after which the assembled unit is placed in the working area of the inductor pos. 3, fig. 1 a.
Figure 1. Stages of magnetic-pulse crimping of multicore cables: 1 - ferrule; 2 - stranded wire; 3 - inductor; PCG - pulse current generator; \(I_d\) - discharge current; \(H\) - magnetic flux; \(I_i\) - induced current; \(P_m\) - magnetic pressure, \(\Delta_1, \Delta_2\) - air gap in the working area of the inductor before and after exposure.

At the second stage, the energy accumulated in the pulse current generator (PCG) is discharged to the inductor tool. When the discharge current \(I_d\) is passed through the inductor 3, an alternating magnetic flux \(H\) arises, which induces the induced currents \(I_i\) in the walls of the tip 1. The interaction of \(H\) with \(I_i\) leads to the appearance of a magnetic pressure \(P_m\) acting in the radial direction, fig. 1 b.

The magnetic pressure \(P_m\) plastically deforms the assembled unit in the working area of the inductor, carrying out a uniform crimping of the connecting tip with the cable cores, filling the voids in the connection area, fig. 1 c.

The nature of the current discharge and the effect of magnetic pressure during MPC is shown in fig. 2. The discharge current has a sinusoidal damping character, since energy is released to the L-R-C circuit, the magnetic pressure is damped in amplitude and affects the workpiece in a positive half-cycle [11, 12].

When the induced current flows in the walls of the tip, the deformation of the heated walls of the connecting tip is improved. At the same time, due to high-speed plastic deformation, the tip walls are cold worked [13].

To assemble stranded wires with a cross section of up to 95mm² with lugs, it is necessary to use a PCG with an energy capacity of up to 10 kJ, a natural discharge current frequency of 20 kHz and an amplitude value of the discharge current up to 200 kA [14].
The dependences of the mechanical strength and contact resistance of the connection on the input energy of a tinned copper tip with aluminum stranded wires of various sections are shown in figure 3.

![Graph showing the dependences of the mechanical strength and contact resistance on pulse energy.](image)

**Figure 2.** Cyclogram of the discharge of current and magnetic pressure during MPC

- $T_d$ - discharge current period

![Graph showing the cyclogram](image)

**Figure 3.** Dependences of the contact resistance $R_r$ (a) and the mechanical shear strength $P_s$ (b) on the pulse energy $W$ for the cross-sections of stranded wires: 1 - $S = 95\text{mm}^2$; 2 - $S = 50\text{mm}^2$; 3 - $S = 35\text{mm}^2$

With an increase in the input energy, the area of physical contact between the wall of the tip and the cable cores increases, the contact resistance $R_r$ decreases, and the strength of the connection increases.

At an energy of more than 12.3 kJ, the cable cores are destroyed (breaking off) and cracks appear in the walls of the tip.

With insufficient energy (less than 9.4 kJ), there is no tight connection.

The obtained values of transient resistance and mechanical strength meet the requirements of OST 1 03967.

A general view of an experimental sample of a multicore cable with a ferrule at various stages is shown in figure 4.
Figure: 4. General view of an experimental sample of a multicore cable with a tip cross-section 
$S = 95\text{mm}^2$: at the stage of assembly; b - after MPC; c - after pull-out tests

The technology for assembling cables of various cross-sections with ferrules by the method of magnetic-pulse processing can be used in the production of on-board cable networks, in the electric power industry when creating and repairing power networks (cable and overhead lines), in instrument making, aircraft construction, automotive industry, at machine-building enterprises of the defense complex [15].

The use of a dosed introduction of energy provides a denser packing of conductive cores in the contacts, which makes it possible to reduce the transition resistance, reduce losses for ohmic heating, and ultimately increase the reliability of cable networks.

3. Multi-junction magnetic-pulse pressure testing of metal-glass and metal-ceramic units

In the manufacture of electronic products, instrumentation, it is necessary to combine materials in a heterogeneous combination: metal-ceramic or metal-glass.

The use of traditional methods for assembling joints (diffusion welding, rolling with rollers) is ineffective and leads to irrational high costs of materials and energy [16]. Mechanical stress on the assembly leads to cracks, breakage of glass or ceramics. It is proposed to assemble such units using the energy of an electromagnetic field [17].

In the process of magnetic-pulse assembly, parts made of glass or ceramics are combined with metal into a mechanically strong one-piece assembly due to plastic deformation of the covering electrically conductive shell (copper nickel). When using severe plastic deformation in the assembled unit, stress concentration centers appear, initiating the occurrence of cracks, which is unacceptable.

The authors of the article proposed that the assembly of metal-glass units (MGU) be carried out with several pulses at energies of 100-200 J [16].

When sampling the gap between the electrically conductive shell and the glass frame, due to the induced induced currents, the metal is plastically deformed and heated. After cooling, it is assembled with an interference fit in the joint without destroying the glass base.

An example of the assembly of a metal-glass assembly - a fuse is shown in figure 5.
The composite metal-ceramic assembly (MCA), figure 6, is a body and insulating element of a microwave electric vacuum device, which must ensure operability at voltages over 10kV and intense thermal loads.

Analysis of literature sources showed that when exposed to metal-ceramic assemblies by mechanical methods: crimping with cams, rolling with rollers, in beryllium ceramics, stress concentration centers arise, leading to the destruction of ceramic rods, which is unacceptable in the production of ultra-high-frequency electric vacuum devices.

As a result of the research, it was revealed that the process is not realized in one transition, since when the required configuration of the metal shell is reached, microcracks are formed in the ceramic rods as a result of intense loading [18].

To obtain high-quality joints, the conditions for high-quality pressing of metal shells on brittle bases were formulated [16]:

\[ U_f [u]; V_{col} \leq [V]; S \geq [S]; J_m \leq [J_{m_{max}}] \]  

They are contradictory, because it is necessary to carry out significant final displacements of the workpiece \( U_f \), which exceed the specified \([U]\) under the constraints of the given velocity \([V]\) and the speed of collision \(V_{col}\) of the shell with the brittle base, constraints of the given impulse of the first half-wave of the magnetic pressure \(J_m\) and the maximum \([J_{m_{max}}]\) and the permissible minimum shell thickness \([S]\) to the given \(S\).
The critical values of the collision velocities $V_{col}$ and the magnetic pressure pulse $J_m$ were established on an empirical basis. For various materials of ceramics and glass, their values are in the ranges: $V = 0.5 \div 3 \text{ m/s}$, $J_m = (0.1 \div 2) \times 10 \text{ Ns/m}^2$.

It has also been proved that the conditions for high-quality assembly (crimping) (1) can be realized only with multi-pass processing, i.e. with repeated magnetic-pulse loading with an increase in the magnetic pressure pulse due to the autofrettage of the deformable shell.

The theoretical analysis of the process of magnetic impulse action in the radial direction according to the «crimp» scheme for the MCA was carried out by numerical simulation of a multi-junction magnetic-impulse action by repeatedly solving a one-junction problem. The results of the solution from the previous loading were taken as the initial data [19].

Figure 7 shows the design diagram and configuration of a structural element, as well as the nature of the distribution of magnetic pressure at various stages of the pressure testing process of the MCA. A photo of typical products is shown in fig. 8.

![Figure 7. Distribution of magnetic pressure at different stages of the pressure testing process of the MCA: a - initial state; b - the final stage](image)

Due to cyclic circumferential symmetry, in numerical studies, only a fragment of the product was considered, having the form of a sector with an angle of rotation $l = 2\pi/m$, where $m$ is the number of ceramic rods in the section of the prefabricated structure.

![Figure 8. MCA products obtained by magnetic-pulse pressure testing](image)
Theoretical analysis and experimental studies were carried out using high-speed photo-registration of the process. It was found that the intensity of shaping at each pulse of magnetic loading ceases after the end of the pulse of the first half-period of the current discharge, which is the limiting one during plastic deformation [10].

Analysis of the conditions for obtaining high-quality connections (1) confirmed the assumption that the magnetic-pulse processing should be carried out in series of pulses at low energies, increasing the deflection of the conductive shell, taking into account the increase in the equivalent inductance of the inductor-workpiece system from transition to transition, and also in connection with a decrease in magnetic pressure in the deformation zone due to an increase in resistance to deformation as a result of hardening (work hardening) of the deformable shell [20, 21].

When comparing theoretical studies with the results of high-speed photo-registration of the process, data of the results of measurements and tests of the obtained assembly units, it was possible to identify the areas of variation of parameters that affect the quality of processing: input pulse energy $W = 10\text{kJ}$; operating voltage of the capacitor bank charge $U_o = 0.5 \div 15 \text{kV}$, the number of pulses of magnetic-pulse action $N = 1 \div 10$. These data form the basis for the development of technical requirements for the creation of industrial equipment for magnetic-pulse processing [16, 22].

4. Conclusions
To create composite one-piece axisymmetric compositions - metal, metal-glass and cermet units, it is advisable to use a magnetic-pulse effect according to the «crimp» scheme.

Dependences of the transient resistance and mechanical strength on the input energy have been determined for a wide range of cross-sections of multicore cables with lugs.

The conditions for pulsed loading of metal shells on brittle foundations are obtained, taking into account the multiple magnetic-pulse action by series of small pulses, as well as the range of their variation.

The factors influencing the quality of permanent joints of metal, metal-glass and metal-ceramic units and the area of their variation in order to create industrial equipment for magnetic-pulse action are revealed.

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