ISSN 1068-3755, Surface Engineering and Applied Electrochemistry, 2024, Vol. 60, No. 3, pp. 342–373. © Allerton Press, Inc., 2024.

Chapter 5. Assembly and Mounting of Electronic Modules on Printed Circuit Boards

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Abstract—Automation and mechanization of assembly and mounting of electronic modules yield the greatest efficiency gains in reducing the manufacturing complexity of products. Key pathways to enhance efficiency include the use of automated equipment and batch processing of new component bases, including surface-mount components. The preparation of electronic components for assembly entails several essential operations, including unpacking, incoming inspection, solderability testing, straightening, and lead forming. To ensure the solderability of printed circuit boards, immersion coatings have become widely adopted, achieved through a chemical displacement reaction in solution, providing sufficiently thin and uniform coatings on areas with exposed copper. Notably, immersion silver application involves the inclusion of organic compound additives to mitigate silver migration. Assembly operations require careful coordination of tolerances on lead and hole diameters, selection of an acceptable method for component fixation, and determination of the optimal arrangement of components on the board. The characteristics of universal machines capable of performing these operations are detailed. Furthermore, methods for fluxing, wave soldering of printed circuit boards, soldering with soldering irons, and employing soldering stations are thoroughly discussed. Special considerations regarding the cleaning of assembly joints and boards after soldering are also highlighted.

Keywords: assembly, mounting, electronic modules, printed circuit boards

DOI: 10.3103/S1068375524700054

1. PREPARATION OF COMPONENTS FOR ASSEMBLY

Operations of assembly and mounting are crucial in the manufacturing process of electronic modules as they significantly affect the technical characteristics of the products and are distinguished by high labor intensity (up to 50–60% of the total manufacturing labor). Among these operations, approximately 10% of the effort is dedicated to preparing electronic components for assembly, over 20% to assembly itself, and around 30% to soldering. Automation and mechanization of these operations yield the greatest efficiency gains in reducing the labor intensity of manufacturing. Key strategies for enhancing efficiency include the adoption of automated equipment and the batch processing of new component bases, such as surface-mount components.

Preparation of electronic components for assembly involves several key operations: unpacking, incoming inspection, checking the solderability of leads, straightening, forming, trimming, tinning leads, and placement in the appropriate packaging. Components arrive from the manufacturer in various types of packaging. While a significant portion of this packaging is designed for loading into assembly machine feeders, certain components, including integrated circuits (ICs), are supplied in individual antistatic thermoresistant packaging.

For unpacking ICs with flat leads, machines are employed wherein a thin plastic cover is removed from the package by compressing it transversely with two rods. These rods make contact with the edges of the cover and, as they approach each other, bend it, releasing it from the grip with the package. The freed cover is then carried away into a collection container by a jet of compressed air, while the IC slides down a chute into a receiving cassette.

Resistors and capacitors with axial leads are supplied embedded in a double-row adhesive tape on a fabric base. Embedding into the tape is performed on special machines while observing the polarity of the components. The coil, with a diameter of 245–400 mm and a width of 70–90 mm, contains up to 1000–5000 electronic components. To prevent adjacent windings from sticking together, winding is done with an interleaved separator tape made of cable paper. With the emergence of leadless electronic components, tape pockets with internal cavities have been

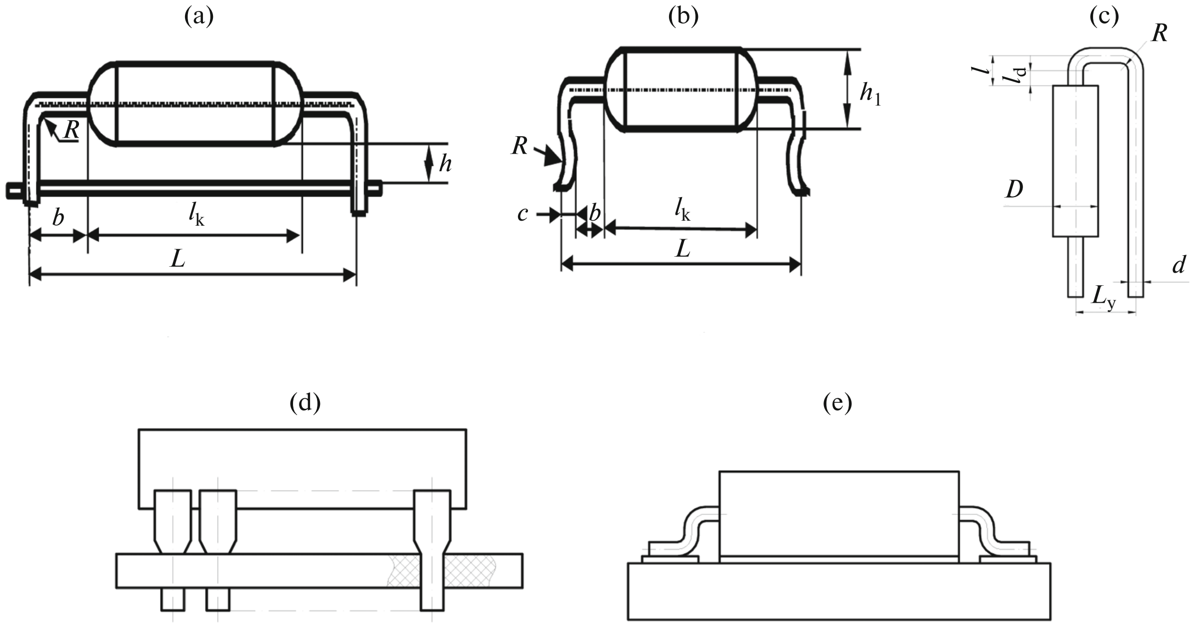


Fig. 1. Options of lead forming and component mounting on boards: (a) 010, (b) 140, (c) 220, (d) 330, and (e) 360.

proposed. The carrier widths are 8, 12, and 16 mm. The pockets are sealed with a polyethylene film using a preheated tool.

The options for forming the leads of electronic components and their mounting on boards should comply with GOST 29137-91 (Fig. 1). Option 010 is used for mounting elements on single-sided boards under significant mechanical loads. In this case, a P-shaped lead forming is used. Option 140 is applied for double-sided and multilayer printed circuit boards. It corresponds to a zig-zag lead forming. For leads with a diameter up to 0.5 mm, $R_{\min} = 0.5$ mm, and for leads 0.5–1.1 mm, $R_{\min} = 1$ mm. Option 220 with vertical mounting is recommended for dense component layout on the board, while option 330 is for integrated circuits in dual in-line package (DIP), and option 360 is for ICs with planar leads.

To fix electronic components on the board, a zig-zag formation is applied to one of the leads of the components in options 140 and 220. The mounting dimension should be a multiple of the pitch of the coordinate grid (2.5 or 1.25 mm) and is ensured by the tool. The maximum deviations of the tool sizes are holes according to $H12$ and $H13$, shafts according to $h12$, bending radii +0.3 mm, and others according to IT 14/2 standards.

The force required to form planar leads is calculated as [1]

$$P = 1.25kb\delta\sigma_{\text{lead}} + P_{\text{clamp}}, \tag{1}$$

where k is a coefficient that determines the state of the surfaces of the punch and matrix (1.0–1.2); b is the lead width, mm; δ is the lead thickness, mm; σ_{lead} is the tensile strength of the lead, MPa; P_{clamp} is the lead clamping force, which is $(0.25–0.3)P$; for type 4 packages, the clamping force is 15 ± 1.5 N per lead.

The zig-zag size C is calculated using the equation [2]

$$C = (d_{\text{hole}} + d)/2 + 0.5, \tag{2}$$

where d_{hole} and d are the diameters of the hole and lead, respectively.

The mechanization of the process for preparing leads for assembly is achieved using technological devices, semi-automatic and automatic machines, selected based on the design of the electronic components and the type of production. In tabletop semiautomatic machines for trimming and forming the IC leads such as ICM 83 (Weresch Automat, Germany) (Fig. 2a), a quick-release tool with a carbide tip and an effective width of 52 mm is employed, which does not require adjustment. Guides for the components are attached using a rapid gripping mechanism, facilitating their replacement for various IC leads. Up to 40 leads can be formed simultaneously at a productivity rate of 3000–8000 units per hour.

The TP6/R OLAMEF trimming and forming machine (Fig. 2b) processes components with diameters ranging from 0.4 to 1 mm, which are supplied on perforated tapes with pitches of either 12.7 or 15 mm. The machine is further equipped with an automatic MOT98 drive with a speed regulator controlled by a pedal, ensuring a productivity rate of up to 20 000 units per hour.

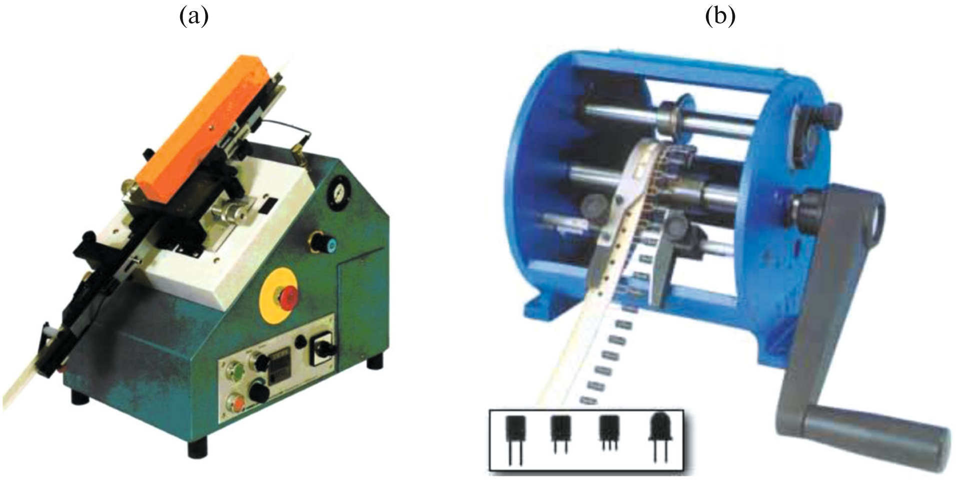


Fig. 2. Tabletop lead forming machines: (a) ICs in cassette and (b) components in tape.

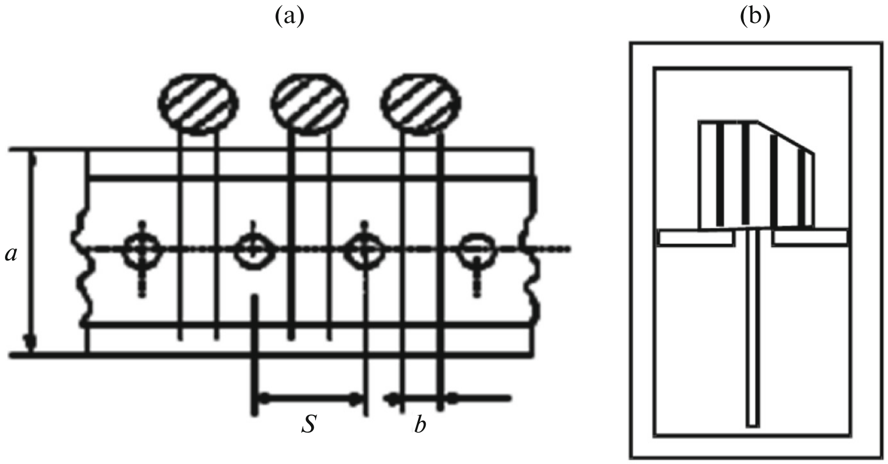


Fig. 3. Packaging of components in (a) a single-row tape and (b) a cassette.

Placing discrete electronic components (ECs) in technological carriers enhances assembly productivity and mechanizes the mounting of components onto boards. Sticky tape is also used as packaging, into which ECs, primarily with axial leads, are glued according to a program. In technological cassettes, ECs are loaded into reservoirs, from where they are fed onto a transport device according to the program. Moving along the transport device, they enter the gluing zone. The machine's productivity is 2400 units per hour, with 2–12 elements per program. The gluing step, denoted as *S*, is a multiple of 5 mm, and the tape width is either 6 or 9 mm. Polarized ECs are glued into the tape in an oriented position (Fig. 3a).

Components with unidirectional leads are glued into a single-row perforated tape, 18 mm wide. The gluing step is 15 mm, with a distance of 2.5 or 5 mm between leads. Transistors and integrated circuits are placed in straight-through single-lever technological cassettes (Fig. 3b).

The adoption of group mechanized processes for soldering printed circuit boards has brought about the issue of the solderability of electronic components. This problem arises due to the heterogeneity of the metals and metal coatings used, their porosity, different storage periods and conditions, varying resistance to environmental exposures, and consequently, different solderability. The diverse solderability of components affects the quality of electromounted connections after group soldering, resulting in significant defects, reaching 5–6%.

To improve solderability, the following methods are employed:

– Immersion melting of electrolytic coatings by submerging them in glycerol heated to 240–260°C or

Table 1. Elements, materials, and modes of tinning

Mounting and structural elements	Materials		Modes	
	Fluxes	Solders	temperature, °C	time, s
Ends of wires and cables	ROM1	61SnPb	250–260	1–4
FPCs, petals, and pins reinforced with press materials	ROMO	33SnPb33Bi, 50SnPb18Cd	170–190 180–200	2–3
Leads of microcircuits and semiconductor devices	ROL1	61SnPb	240–250	1–2
Leads of heat-resistant elements	RENO	61SnPb0.5Sb	250–270	2–3
Mounting elements of PCBs and MLBs	ROMO	61SnPb	250–260 180–190	2–3
Structural elements	ORM1	61SnPb0.5Sb	250–270	3–5
Aluminum alloy parts	ORNO	Sn10Zn, Sn20Zn, Sn30Zn	200–250 280–300 320–350	2–4

active flux, which is effective for low-melting coatings of alloys such as tin–bismuth, tin–lead, or tin–nickel;

– Tinning with tin-based solders using hot air leveling;

– Application of immersion coatings on the leads.

Compared to immersion melting, tinning is a universal, highly effective, and widely used method, as it ensures high solderability without the need for any coatings. Moreover, tinning is the only method for removing gold coatings from component leads, thereby eliminating the risk of intermetallic formation and embrittlement of the joints.

A typical solder tinning process for assembly elements, printed circuit boards, and structural components involves the following operations: fluxing of the surfaces to be tinned, tinning, removal of excess solder, flux residue washing, and drying. Tinning processes are mechanized and involve immersion in solder or passing through a solder wave. Hand soldering is used for individual tinning in small batches of components and for correcting defects in mechanized group tinning.

Fig. 4. Bath for fluxing parts and components.

The key parameters of the process—temperature, time, and the composition of fluxes and solders—are set based on the structural characteristics and the resistance of the tinned elements to thermal loads, fluxes, and solvents for removing their residues (Table 1). The use of solders 33SnPb33Bi and 50SnPb18Cd significantly lowers the tinning temperature for polyester flexible printed cables, thus preventing melting and deterioration of insulating properties. Similarly, for multilayer printed circuit boards, immersion or wave soldering decreases thermal shock and the risk of interlayer connection failure [3].

In small-batch production, small soldering baths made of high-quality steel with a capacity of 850–1000 g of solder are used, maintaining the melt temperature in the range of 100–500°C at a specified level. The thermally insulated frame of the bath ensures high safety and increases the efficiency of tinning parts. The waste collector surrounding the bath frame provides a clean working area (Fig. 4).

Excess solder is manually removed using a scraper or by shaking, as well as through centrifugation. During centrifugation, excess liquid solder is removed from tinned surfaces under the action of centrifugal forces, eliminating manual labor techniques, improving working conditions, lending itself to automation, and ensuring consistently high coating quality independent of the operator’s skill level. Centrifugation enables the adjustment of coating thickness by varying the rotation speed of the centrifuge shaft.

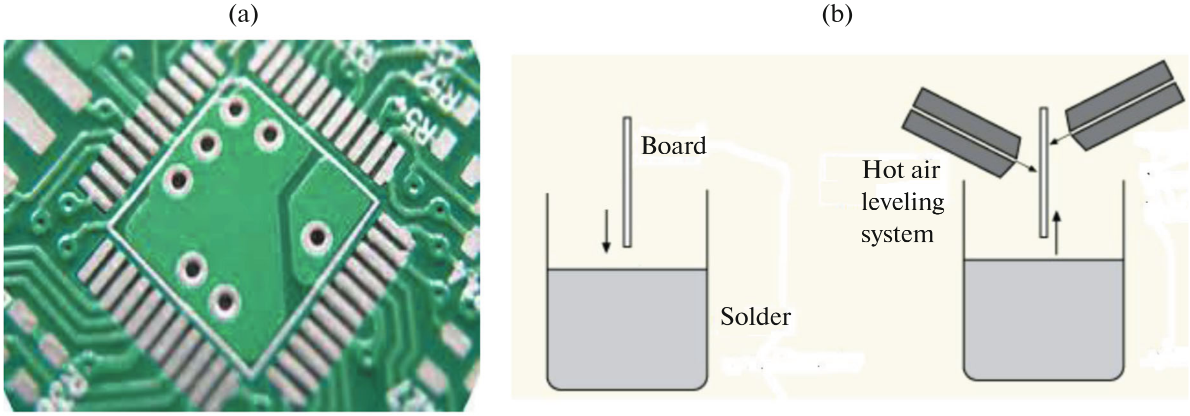


Fig. 5. (a) Appearance of the board after solder leveling and (b) HASL scheme.

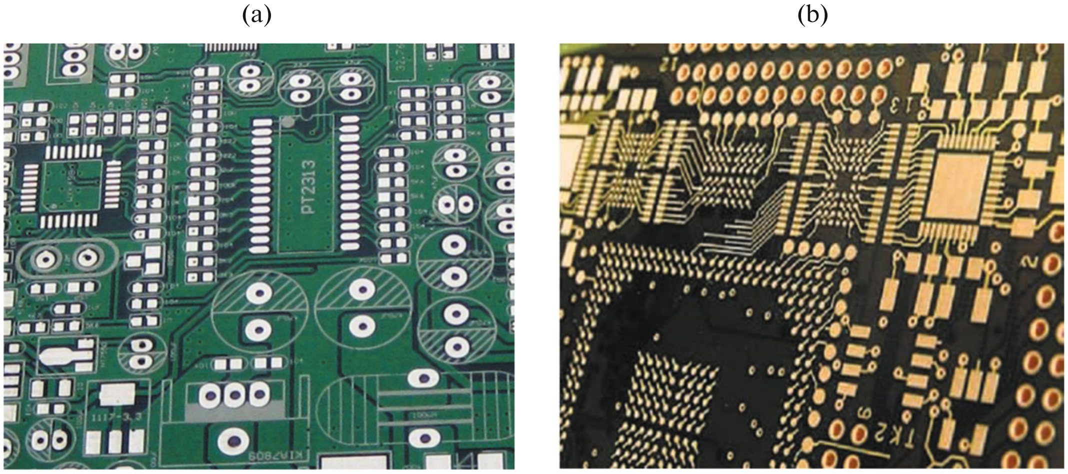


Fig. 6. Boards with (a) an immersion silver coating and (b) ENIG.

Until recently, coating with solder and hot air solder leveling (HASL) predominated in the electronics industry due to the excellent solderability characteristics of the tin–lead alloy and its relative affordability compared to noble metal-based coatings. In the conventional HASL process, the contact pads of the board are covered with a layer of eutectic tin–lead alloy typically ranging from 1 to 40 μm in thickness, while excess solder is blown away by hot air streams (Fig. 5).

A drawback of HASL is the unevenness of the coating, caused by the formation of solder bridges, leading to the formation of nonflat contact pads. This defect can result in the misalignment of solder paste prints and electronic components. Solder bridges can form between contact pads with a small pitch (0.5 mm or less).

Among other drawbacks of this type of finishing coating, the presence of lead stands out, as it is one of the most toxic metals and is prohibited for use within the European Union under the RoHS directive. Additionally, hot air leveled coating does not meet the flatness requirements for mounting contact pads for microchips with very high integration levels. This coating is unsuitable for the technology of wire bonding of chips to the board.

To ensure the solderability of printed circuit boards, immersion coatings have become widely adopted. These coatings, obtained through a chemical displacement reaction in solution, yield sufficiently thin and uniform layers on regions with exposed copper. The process of applying immersion silver involves the addition of organic compounds to prevent silver migration. The thickness of the silver coating does not exceed 0.2 μm. While silver coatings have a relatively long service life, they may yellow due to contamination from sulfates and chlorides in the air (Fig. 6a).

An electroless nickel immersion gold (ENIG) coating, consisting of a thin (0.05–0.2 μm) gold layer deposited over a nickel underlayer (4–5 μm), offers superior flatness compared to HASL while maintaining good solderability [4] (Fig. 6b). Gold dissolves well

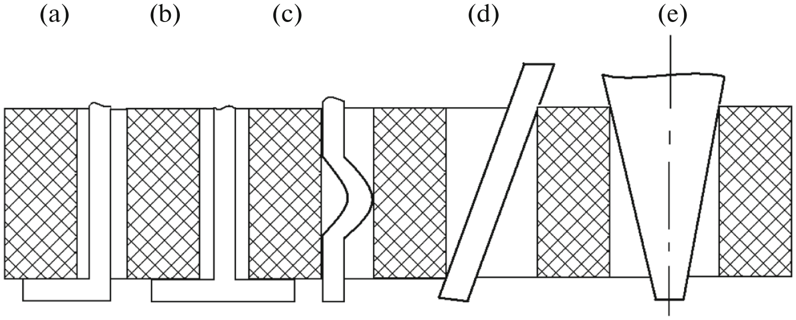


Fig. 7. Fixation of component leads in board holes.

in solder, is resistant to rapid tarnishing and oxidation, making it an excellent choice for a finishing coating. Three types of defects associated with ENIG finishing coatings are known: porous gold coating, gold embrittlement, and the “black pad” effect. During the nickel reduction on the copper surface, phosphorus may be released. During soldering and gold dissolution into the solder, this phosphorus surface layer is exposed, causing the solder to not wet its surface and roll off.

The fluxing of electronic component leads in the technological assembly process of radioelectronic equipment largely determines the reliability of soldered joints. However, existing fluxing processes do not always ensure high-quality coating of components with long storage times due to the inability to use active fluxes such as LTI-120, which subsequently cause corrosion of the leads of components and microchips. Therefore, ultrasonic fluxing is employed to restore the solderability of coatings after prolonged storage.

A prerequisite for the ultrasonic fluxing process is the presence of a protective environment in the fluxing zone. This is because under ultrasonic vibrations, there is intense oxidation of the solder surface, and some of the oxides formed remain on the leads of the microchips after fluxing. The optimal conditions are as follows: displacement amplitude of the emitter tip 10–12 μm, frequency 44 kHz ± 0.15%; distance between the emitting surface of the preconcentrator and the leads of the microchip 1.5 ± 0.5 mm; protective gas (argon) flow rate 3×10^{-5} m^3/s [5].

2. MOUNTING COMPONENTS ONTO BOARDS

The mounting of electronic components and integrated circuits onto boards represents the initial phase of assembly, and defects arising from this operation can affect the quality of mounting connections. Depending on the technical implementation, manual and mechanized assembly of modules are distinguished, with the selection of equipment being determined by the type of lead configuration (pin, planar). Achieving high-quality component mounting on boards necessitates the alignment of tolerances on leads and hole diameters, the selection of an appropriate method for component fixation, and the determination of the optimal arrangement of components on the board. During automated assembly of single-sided and multi-layered boards, the following technical requirements must be met:

– Minimization of component versions to the lowest possible number;

– Arrangement of packaged ICs on the printed circuit board in rows or a staggered pattern with a placement pitch of 2.5 or 1.25 mm; gaps between IC packages should be no less than 1.5 mm;

– Mounting of ICs with pin leads only on one side of the PCB, while those with planar leads should be installed on both sides.

The position of components after assembly should remain unchanged until the moment of contact, i.e., the formation of the mounting connection. Therefore, components must be secured to the board. The fixation process should be simple to perform, eliminate the need for extra components, withstand the weight of the components, and be carried out during the backward motion of the working tool. There are various methods for fixing component leads in board holes (Fig. 7): (a) bending, (b) flattening, (c) deformation, (d) using elastic forces, or (e) friction. Bending poses a higher risk of short circuits with nearby conductors compared to flattening. Spring leads of DIP packages do not require bending, as fixation is achieved through friction against the inner walls of the holes. For ICs with planar leads, preadhering them to the board is a common fixation method.

Manual, semiautomatic, and automatic methods are used for mounting ECs and ICs onto boards. To increase productivity in small-batch production, assembly tables with assembly software are utilized. These tables provide assembly personnel with visual aids displaying information about component place-

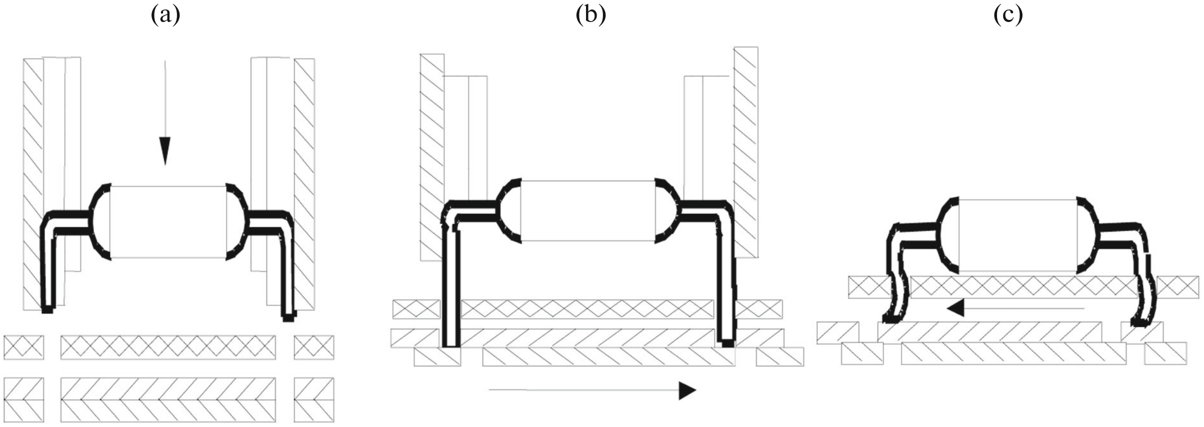


Fig. 8. Mechanized component mounting with axial leads: (a) lead alignment, (b) lead trimming, and (c) lead bending.

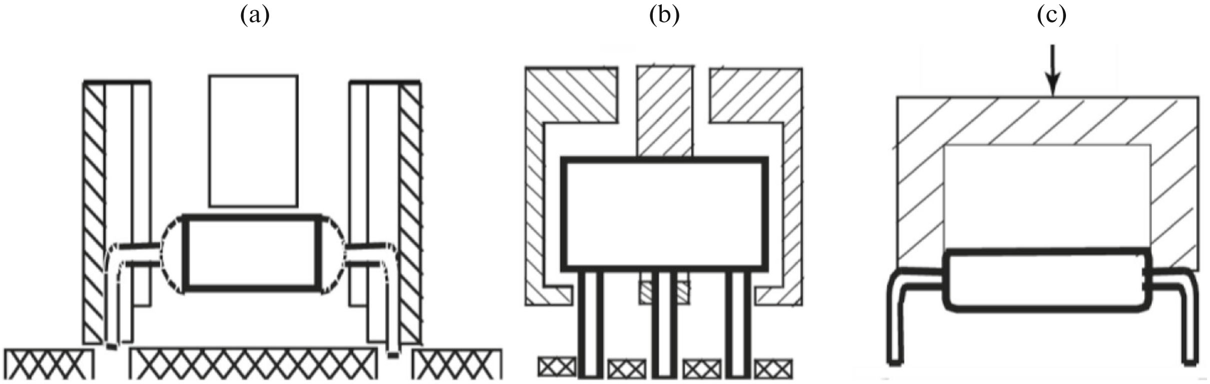


Fig. 9. Component positioning options with assembly heads: (a) for two leads, (b) for three leads, and (c) by package.

ment and assembly sequence. The productivity of component mounting can reach 500 units per hour.

In mechanized component mounting, the assembly head plays a primary role. It performs the following functions (Fig. 8): it receives components from the feeding device, orients them, straightens and trims the leads, inserts the leads into corresponding holes or aligns them with contact pads, and if necessary, bends them.

The positioning options (Fig. 9) depend on the design of the components. Components with lateral leads are positioned using two leads, gently guiding the element toward the board. For components with multiple pin leads (transistors), multiple leads are positioned, requiring larger tolerances on the board holes. Integrated circuits are installed by holding onto the package, which is a less reliable method.

The performance of the positioning head significantly depends on the tolerances of all components. When mounting components with pin leads, a series of tolerances affect the effective deviation of the lead end. Assuming that the minimum width b_{guide} of guide *2* is is the maximum width b_{lead} of lead *1* (preventing lead jamming in the guide) (Fig. 10), the resulting chain of tolerances yields a shift of the component lead midpoint from the ideal pitch δ_{A1} in the x direction,

$$\delta_{A1} = \delta_{A2} + \delta_{A3} + \delta_{A4} + \Delta b_{\text{guide}} + \Delta b_{\text{lead}}, \qquad (3)$$

where δ_{A2} is the tolerance for the position of the guide, δ_{A3} is the tolerance for machine vibrations, δ_{A4} is the tolerance for reciprocating movement, and Δb_{guide} and Δb_{lead} are the tolerances for the width of the guide and lead, respectively.

Since there can be no jamming for the guide in the y direction, then

$$\delta_{A1y} = \delta_{A2} + \delta_{A3} + \delta_{A5} + 1/2\left(\Delta b_{\text{guide}} + \Delta b_{\text{lead}}\right), \qquad (4)$$

where δ_{A5} is the positioning tolerance.

Tolerances δ_{A1x} and δ_{A1y} for the deviation of the guide, tolerance δ_{A4}, and the tolerance for the position

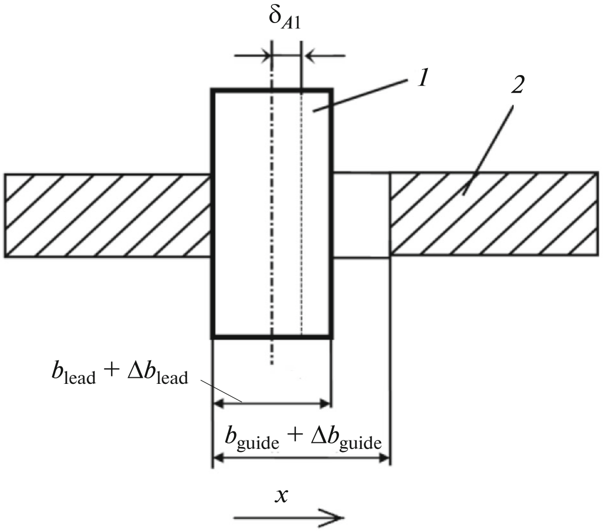


Fig. 10. Positioning of a lead relative to the guide.

of the mounting hole δ_{01}, enable the calculation of the required diameter of the mounting hole [7],

$$d_{01} = 2\sqrt{\delta_{A1x} + \delta_{01} + \delta_{A4} + 0.5\left(b_{\text{lead}\,x} + \Delta b_{\text{lead}}\right)^2} + \sqrt{\delta_{A1y} + \delta_{A1} + \delta_{A4} + 0.5\left(b_{\text{lead}\,y} + \Delta b_{\text{lead}}\right)^2}. \quad (5)$$

Under conditions of multi-item and small-batch production of electronic systems, the use of specialized automatic and semiautomatic machines is economically unfeasible. Therefore, programmed manual assembly is employed on light assembly tables, where lighting tools indicate the cell of the fixed storage and the area of the PCB where the component needs to be fixed. Manually, without special equipment, the typical assembly rate ranges up to 200 components per hour, while on the light assembly table, it reaches 500–600 units per hour. There is no need to refer to the drawing; placement errors of components are eliminated; the qualification requirements for workers are leveled down.

Various principles of component feed, indication of locations on the PCB, and control of board movement can be applied in a light assembly table (Fig. 11). Indication of component placement locations on the board is carried out using either a light pointer or a laser beam. The polarity of elements is indicated by the flashing of the beam. In a flexible system utilizing a light pointer, the spot of the light beam from the projector moves across the PCB at a speed of 300–400 mm/s with a resolution of 0.15–0.3 mm. The beam can generate different symbols and indicate the mounting location.

The Logpoint light assembly table (Fig. 12a) comprises a light beam head, a worktable, a computer, a display, a keyboard, and an elevator storage unit. Programming is carried out in a step-by-step mode, and all data are displayed on the display screen. In the Royonic programmable assembly light table, the component placement locations on the board are indicated using a laser beam (Fig. 12b).

Assembly machines, which perform the primary technological operation of mounting electronic components onto the board (Fig. 13a), exhibit a higher level of automation in assembly and mounting tasks compared to light assembly tables. Their application

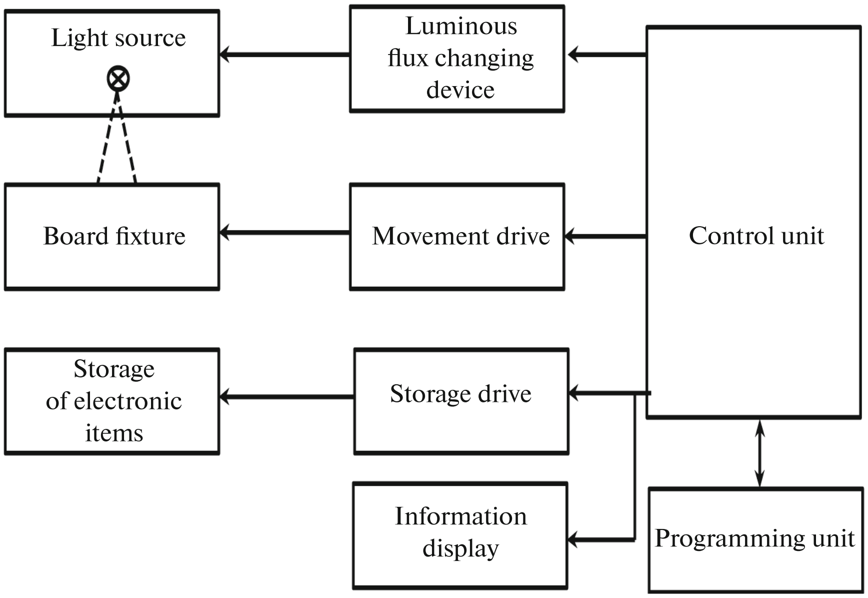


Fig. 11. Diagram of a light assembly table.

Fig. 12. Light assembly tables (a) Logpoint and (b) Royonic.

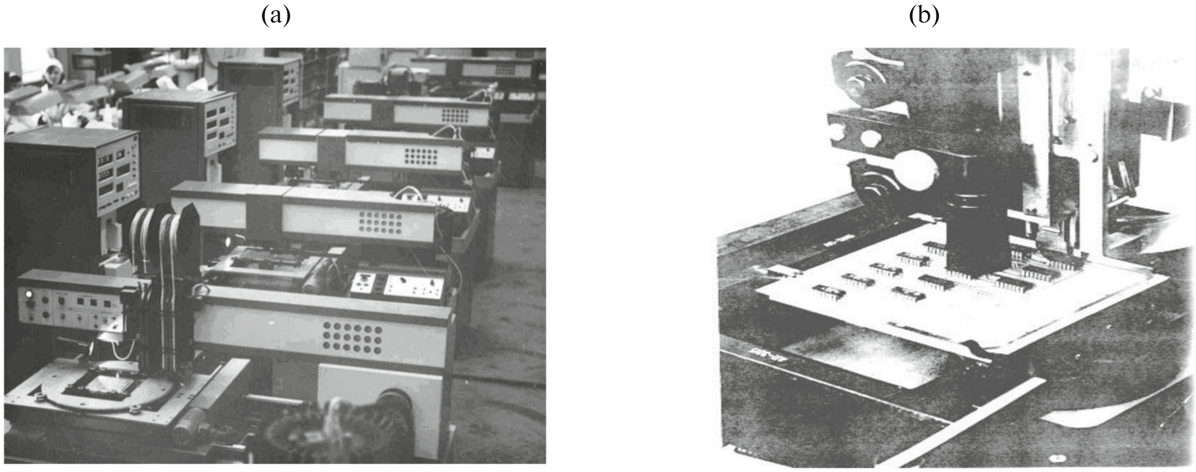


Fig. 13. (a) Machines mounting component from tape and (b) assembly head.

becomes justified in conditions of serial or large-scale production. Typically, they are flexible and versatile machines, where assembly heads can mount various ECs onto the PCB (Fig. 13b).

In an automatic cycle, assembly heads can perform several technological operations: extracting electronic components from storage or carriers, rotating components by key or coordinate axis, shaping leads, transferring ECs, centering, and mounting them on the PCB. Components with axial leads are mounted before components with radial leads because, typically, the former are smaller than the latter. Since the tools for mounting on the PCB used for components with axial leads are also smaller in size, such a mounting sequence promotes high assembly density.

In small-batch production, universal machines such as the Cencorp 1000 OF EVO (Fig. 14) are used, where components with radial and axial leads are fed from tape or trays, as well as SMD components from an 8-mm tape. The automatic change of mounting tool occurs according to the program. The machine performs lead forming of components, and if necessary, their bending from the backside of the board. When reading 2D and 3D barcodes from the printed circuit board, its position in the machine is corrected. The assembly throughput is 2600 units per hour, with a repeatability of ±0.03 mm.

In serial and large-scale productions, machines are employed to determine programmatically the sequence of mounted components by transferring them from primary tapes (sequencers). Mounting

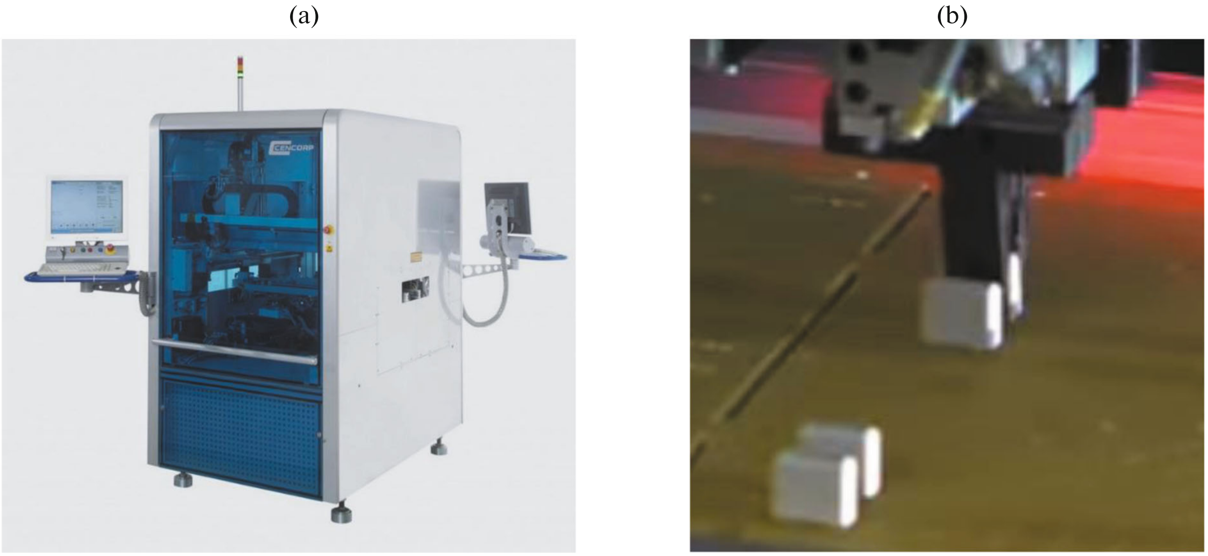

(a) (b)

Fig. 14. (a) Universal machine and (b) radial lead component mounting.

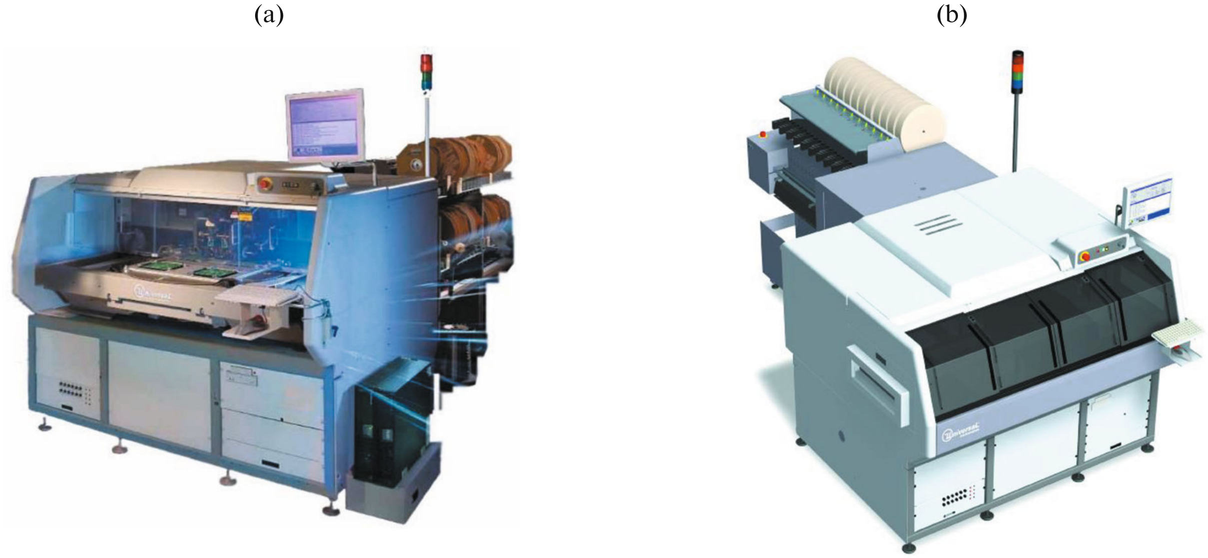

(a) (b)

Fig. 15. Radial sequencer mounting machines.

machines-sequencers exhibit a high level of productivity and mounting quality, typical of automatic mounting equipment like the Universal Instruments' 8th generation for leaded components (Fig. 15). With a nominal throughput of 26000 components per hour (0.14 s/component), these machines rank first in terms of speed of mounting radial components.

It is feasible to control the electrical parameters of the electronic component directly before transfer, thus preventing the installation of incorrect component types. The machine cuts components from the axial tape (52 mm width), aligns them in the specified sequence, and then feeds them to the mounting head for installation. The number of component types ranges from 20 to 200 (with 20 input stations).

3. FLUXING IN WAVE SOLDERING

Auxiliary operations in the batch soldering process include degreasing, mask application, fluxing, mask removal, flux cleaning, drying, and inspection. During degreasing, the board is immersed in an organic solvent for 7–10 s, ensuring that the top side is covered with a layer of solvent of at least 0.5–1.0 mm.

Fluxes are manually applied to the soldering surfaces using a brush, dispenser, or mechanized roller application, or by immersion in flux, liquid, or foam flux waves. Brush or dispenser fluxing is used for tinning small batches of components and for correcting defects in batch tinning using soldering irons.

The batch flux application is employed for fluxing components, flexible printed cables, and printed circuit boards. Regardless of the flux application method used, the process must ensure uniform wetting of the entire surface of the component with flux. The flux should be applied in sufficient quantity to enable subsequent tinning of the designated surface.

The fluxing process for unpressurized assemblies must prevent flux from seeping inside and from reaching the contact surfaces of connectors and relays. Flux should not be applied closer than 3 mm from the end of insulation on wire and cable terminations.

Fluxing of printed circuit boards is carried out using immersion in a flux bath, rotating brushes, spraying, wave soldering, or foam application. Immersion flux application is low in productivity and does not ensure uniform and consistent coverage of the board with flux. It requires precise control of the depth of immersion of the board into the flux. Therefore, this method is used in small-batch production.

Flux application using rotating brushes mechanizes the fluxing process (Fig. 16). However, inactive parts of the brushes that are not submerged in flux may dry out and accumulate lint when the device is stopped.

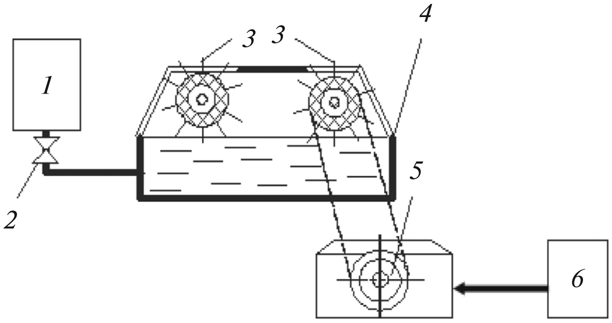


Fig. 16. Fluxing with rotating brushes: (*1*) flux tank, (*2*) valve, (*3*) brushes, (*4*) bath, (*5*) reduction gear, and (*6*) motor.

Flux application by spraying with a single pair of nozzles at a distance of 300 mm from the board ensures the fluxing of boards up to 100 mm in width. For wider boards, two, three, or more pairs of nozzles are used. In the flux application setup by spraying (Fig. 17), flux from reservoir *1* flows through valve *2* into electromagnetic valve *3*, then into adjustable jet device *4* and dosing nozzle *5* of the sprayer. The flux is then entrained by the airflow exiting from the air nozzle *6* of the sprayer. Compressed air is supplied through pressure regulator *9* and receiver *10.* Mainline *8* is used for purging the channels of the valve, jets, and nozzle in case of clogging by flux residues [7].

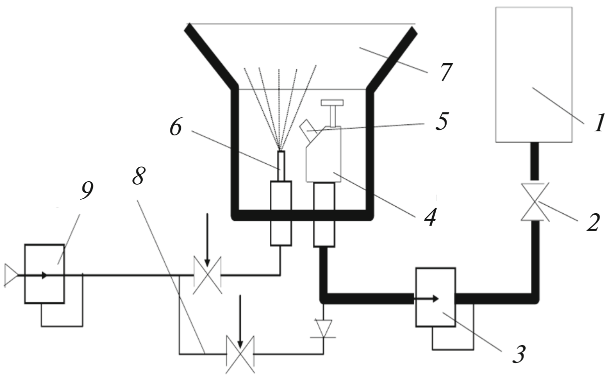


Fig. 17. Spraying fluxing.

The equipment for applying flux as foam (Fig. 18) consists of inner reservoir *1* and outer reservoir *2*, interconnected so that the liquid flux *3* freely flows from one compartment to another. Inside the inner reservoir, closely linked foaming elements *4* are installed, made of porous materials (such as ceramics, felt, or fleece) in the form of discs or tubes. When compressed air is supplied through the hole in element *4*, the flux inside the inner reservoir is foamed into a “foam cap” *7* above the reservoir.

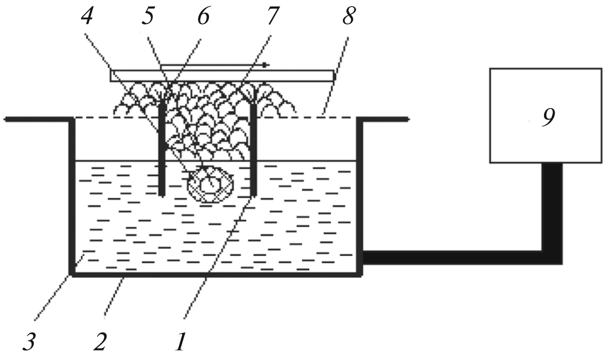


Fig. 18. Foam fluxing.

The outer reservoir is covered with mesh *8*, which facilitates the accelerated reversion of foam back into liquid. Vertical brushes *6* are used to maintain a uniform level of foam surface above the outlet. Flux consumption is replenished from reservoir *9*. A crucial factor for the formation of a uniform foam crest height is the uniformity of cell sizes in the porous material from which the foaming elements *4* are made.

In the device for generating a flux wave (Fig. 19), flux is supplied using a rotating impeller *1* connected to an electric motor *2.* Board *3* moves along the conveyor towards the standing flux wave *4*, which forms at the outlet of channel *5* located in bath *7.* The height of

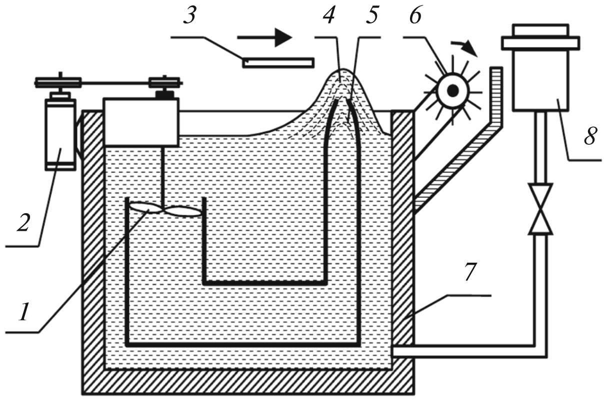


Fig. 19. Wave fluxing.

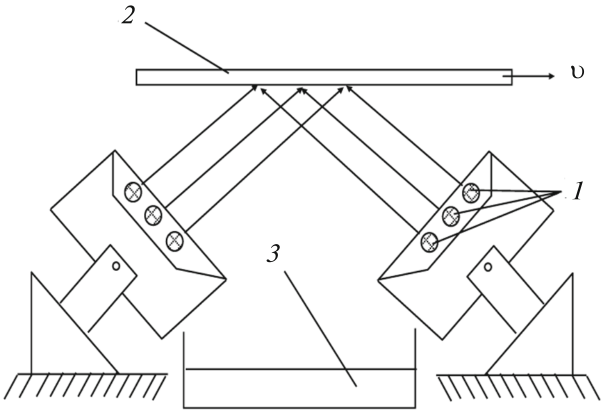


Fig. 20. Board drying with IR heating: (*1*) IR emitters, (*2*) board, and (*3*) flux collector.

the wave is regulated by adjusting the speed of the electric motor.

The high-pressure flux stream not only covers the bottom side of the board but also ensures penetration into the metalized holes of multilayer boards. Excess flux is removed from the board with brush *6*. Flux is supplied to bath *7* through a valve from reservoir *8*. Drawbacks include the complexity of the setup and increased dimensions of the soldering line. Fluxing with a foam wave involves the entire mass of flux in an open bath with a large surface area for the evaporation of volatile components. The foaming wave is generated by a slit nozzle through the foaming of liquid flux with numerous air jets supplied into the tube made of fine-pored ceramic at pressures ranging from 0.01 to 0.03 MPa.

Drying of flux before soldering, combined with preheating of printed circuit boards, largely determines the quality of solder joints, especially in large-scale and mass automated production. Since fluxes typically contain solvents such as alcohol and water with boiling points of 80 and 100°C, respectively, when liquid flux comes into contact with molten solder at temperatures of 230–250°C, vigorous boiling of the flux occurs, releasing a significant amount of gases and vapors.

Gas cavities and vapor pockets form in the solder, leading to porosity in the joint. Additionally, the surface layers of solder in contact with the liquid flux significantly cool due to its evaporation, which worsens the wetting of the printed circuit board surface.

Therefore, it is crucial during flux predrying to ensure complete solvent evaporation from the flux composition. This task is achieved by heating the bottom (soldering) surface of the boards to a temperature of 85°C if the solvent is alcohol and 100°C if the solvent is water. Preheating the boards before soldering brings down thermal shock at the moment of board contact with the molten solder, minimizing board warping and lowering the soldering temperature.

The boards are heated in infrared (IR) drying chambers (Fig. 20), where thermal radiation from IR lamp *1* is reverberated by a reflector and directed onto board *2*. Excess flux drips into collector *3*. To improve heating uniformity, a convective airflow is created by a fan. A disadvantage is the occurrence of smoking, which decreases the intensity of IR radiation. To avoid this, IR emitters are angled relative to the horizontal surface of the board, and special collectors are installed for excess flux, which are easy to clean.

4. WAVE SOLDERING ELECTRONIC MODULES ON PRINTED CIRCUIT BOARDS

Wave soldering is the most common method in the industry for soldering electronic modules onto printed circuit boards in large-scale and mass production. The advantages of this method include high productivity due to mechanized board movement relative to the solder and the ability to automate the entire operation cycle: degreasing, fluxing, preheating, soldering, flux cleaning, and drying. Furthermore, it involves the interaction of the board with a clean solder surface in a short period, reducing thermal shock, dielectric warping, and component overheating. Drawbacks include the large mass of solder in the wave (100–500 kg), increased equipment dimensions, and greater solder oxidation.

The technological fundamentals of wave soldering are defined by the interaction between the solder wave and the board. The key condition for achieving high-resolution wave soldering, allowing the soldering of boards with small gaps between printed conductors without the need for bridges, solder bridges, or solder balls, is the creation of a thin and uniform layer of solder on the board conductors, facilitating the formation of "skeleton" solder joints. The soldering process consists of three stages: entry of the board into the solder at an angle α (point *A* in Fig. 21), contacting with the

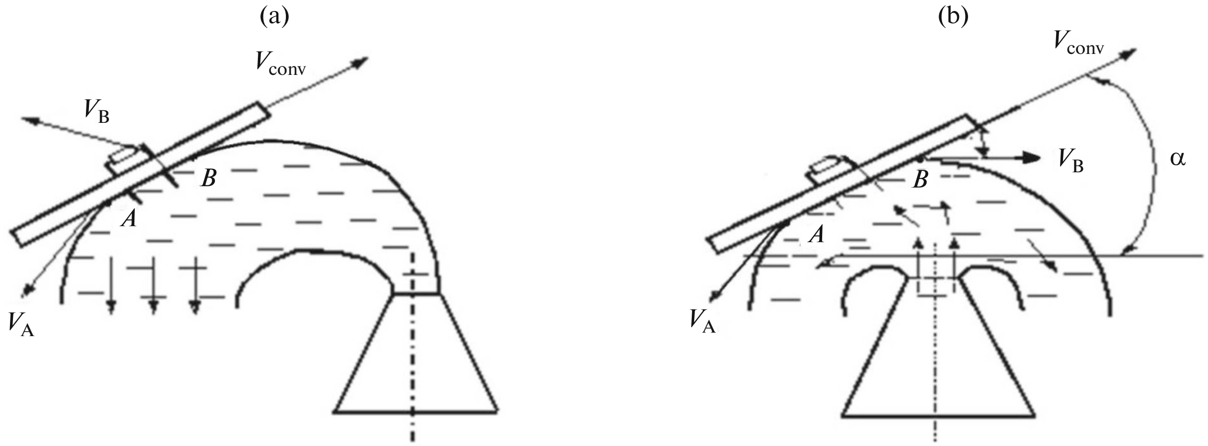


Fig. 21. Interaction of (a) single-sided and (b) double-sided waves with a board.

solder (segment *AB*), and exiting from the solder (point *B*). During the first stage, the direction of wave fluxing V_A facilitates the removal of flux vapors from the reaction zone (both in symmetrical two-sided and directed one-sided waves). During the second stage, the spread of solder along the board *AB* combined with the conveyor speed V_{conv} determines the soldering time. In the case of a two-sided wave, this time is longer, ensuring a more complete filling of the metalized holes with solder. However, increasing the interaction time also increases the solder thickness on the printed conductors up to a certain limit [7].

The final formation of the layer thickness occurs at the exit of the board from the solder wave at point B. In this case, in a one-sided wave, the longitudinal component of the spouting velocity V_B is subtracted from the conveyor speed, while excess solder is washed off and the solder layer becomes thinner.

Wave soldering time is calculated as

$$t_{sold} \le 0.06\frac{L_{conv\,(mm)}}{V_{conv}\left(\dfrac{m}{min}\right)} \le \frac{0.06B\cos\alpha}{V_{conv}}, \quad (6)$$

where L_{conv} is the distance from point *A* to point *B*, V_{conv} is the conveyor speed, and *B* is the wave width.

In the case of a one-sided wave, a horizontal conveyor position, a shallow wave shape, and possibly a higher solder circulation rate are more favorable. The depth of immersion typically ranges from 0.6 to 0.8 times the board thickness but can reach 1.5 to 2.0 times the board thickness with a frontal baffle in the cassette. The conveyor speed ranges from 0.5 to 1.5 m/min. In a two-sided wave, the velocity V_B adds to the conveyor speed V_{conv} (up to 2.5 m/min), contributing to the formation of solder bridges. Therefore, in a two-sided wave, efforts should be made to increase the angle of inclination, steepen the wave profile, and decrease the solder spouting velocity.

In electronic assembly technology, alongside one-sided and two-sided parabolic waves, waves of other profiles are employed, such as flat (or wide), secondary (or “reflected”), delta, lambda, and omega waves. A *flat* or *wide wave* (Fig. 22a) extends up to 70–90 mm, increasing the contact area between the board and solder, thus allowing for improved process efficiency by raising the board velocity to 3 m/min. Such a wave configuration enables the creation of high-quality solder joints at lower solder temperatures compared to soldering with a parabolic wave. However, a drawback of this wave type is the increased exposed surface area of the molten solder, which promotes the formation of oxide films in the solder. A *secondary wave* (Fig. 22b) is formed by an inclined reflector on one side of the nozzle, which maintains a specific amount of solder in the form of a lower-height wave. The temperature in the secondary wave is lower than in the main wave. Interaction between the board and the secondary wave leads to the reflow of solder bridges and the resoldering of joints. A *delta wave* (Fig. 22c) is characterized by solder flow in one direction, achieved by elongating one side of the nozzle and applying greater solder pressure, resulting in a deeper wave. This wave is used for soldering components with elongated leads, such as through-hole connectors. A drawback is the significant dependence of the wave height on the solder feed rate and the difficulty of maintaining it at a constant level.

To generate a *lambda wave* (Fig. 22d), proposed by the Electrovert Company (Canada), a nozzle of complex shape is employed, featuring a steep solder drain towards the board side and a long, nearly horizontal wave profile at the exit end of the board. Upon entry of the board into the wave, there is a swift flow of solder, possessing excellent wetting action and penetration capability. At the exit, the board’s relative speed to the

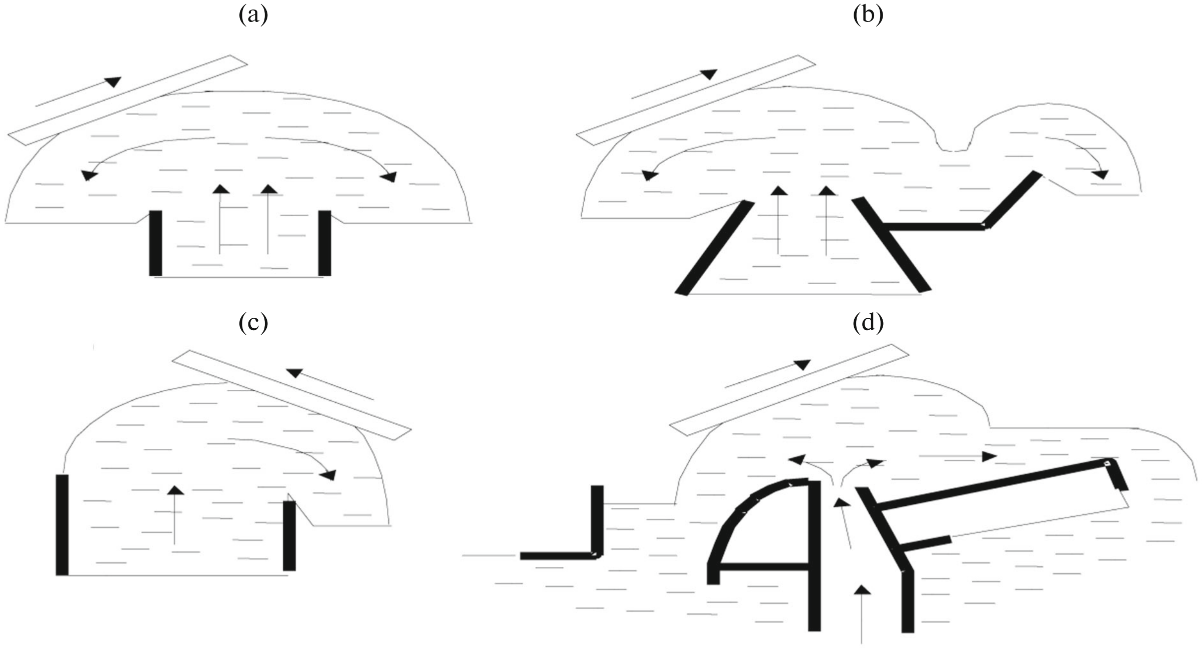


Fig. 22. Wave profiles for group soldering.

solder is practically zero, and the gradual increase in the angle between the board and the solder surface eliminates the formation of solder bridges and spatter. Such a wave profile, with a height ranging from 13 to 19 mm and a conveyor speed of up to 5.4 m/min, enables high-quality soldering of multilayered boards with dense component placement.

Based on the lambda wave, an *omega wave* has been developed by incorporating a vibrating element into the nozzle aperture through which solder is dispensed. The vibration of the element is generated by an electromagnetic vibrator operating at a frequency of 60 Hz with an oscillation amplitude of 1–3 mm. By imparting turbulence to the solder wave, the conveyor speed is increased to 6 m/min, ensuring the filling of plated through-holes in the boards up to 99%, and reducing the number of defects such as incomplete solder joints by half.

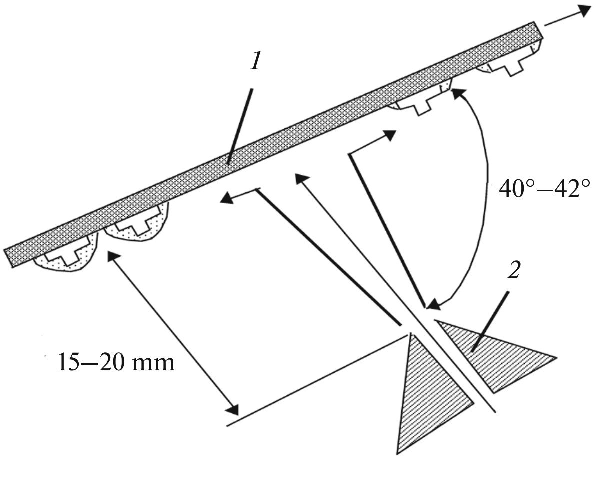


Fig. 23. Hot air solder leveling system.

In the soldering of leadless SMD components, conventional setups fail to fulfill the primary functional objective of wave soldering, which is to leave on the board precisely the amount of solder needed to form a reliable electrical contact. The excess solder remaining on the board leads to the formation of fillet-type joints, which are less reliable than joints with visible contours, as well as solder bridges and balls.

An example of a new approach to mass wave soldering technology is the concept of hot air leveling (Fig. 23). A flow of hot air directed at board *1* removes excess solder, bridges, and balls from its surface. Nozzle *2*, made of stainless steel, possesses sufficient mass to retain heat. Built-in heaters inside the nozzle heat the air to a temperature of 375–390°C at a pressure of 0.3 MPa. The hot air is directed onto the soldered side of the board 6–8 s after it exits the wave, at an angle of 40°–42°, and at a distance of up to 20 mm from the board's surface. Since heating the air entails significant energy consumption, installations are equipped with an automatic system that activates the air supply upon the board's exit from the wave [9].

To limit the amount of solder on printed conductors in mass soldering technology, solder masks in the form of dry photopolymer films with thicknesses of 50, 75, and 100 μm are applied to the surface of the board using vacuum lamination and exposed to ultraviolet radiation. Matte green solder masks have good adhesion to the board surface, prevent the formation of solder bridges, and protect the printed circuit assembly from climatic influences.

An ETS 250 compact conveyor system (ERSA, Fig. 24), equipped with microprocessor control and a touch screen display, is designed for soldering single and/or double waves of molten solder on printed circuit boards of assemblies with surface-mount, through-hole, or mixed mounting. The system sequentially performs fluxing, preheating, and soldering operations with solder waves. A foaming fluxer with automatic flux level maintenance and a built-in compressor ensures uniform fluxing of the board. An air blow-off device is used to remove excess flux. A preliminary medium-wave IR heater dries and activates the applied flux and preheats the board to avoid thermal shock during soldering. The temperature and preheating time are displayed on the touch screen and controlled by the microprocessor control system. The conveyor speed ranges from 0.3 to 2.5 m/min, with an inclination angle from 4° to 7°.

For soldering boards with mixed mounting (components mounted in holes on one side of the board and SMD elements), double wave soldering is applied (Fig. 25).

The first wave is turbulent and narrow, exiting the nozzle under high pressure. Turbulence and high solder pressure ensure good wetting and eliminate the formation of voids with gaseous decomposition products of the flux, but do not eliminate the formation of bridges. The second, smoother wave with low flow velocity eliminates solder bridges and completes the formation of fillets. Therefore, double-wave soldering systems must have separate solder pumps, nozzles, and control blocks for each wave's parameters. Additionally, they are equipped with a HALS system to break solder bridges. The drawback is the significant thermal loads on the board.

For soldering under nitrogen, a SEHO MWS 2340 wave soldering system (Germany) is used, featuring six preheating zones with a total length of 1800 mm, implemented using 3 kW IR modules, a double soldering module, an inert gas supply system, and a microprocessor control unit (Fig. 26). It is designed to work with lead-free solders and solder surface-mount components. Nitrogen consumption is approximately 15 m^3/h, and the oxygen content in the working zone is below 100 ppm. The use of an inert gas protective environment allows for the application of no-clean weakly activated fluxes [10].

Fig. 24. ETS 250 wave soldering machine.

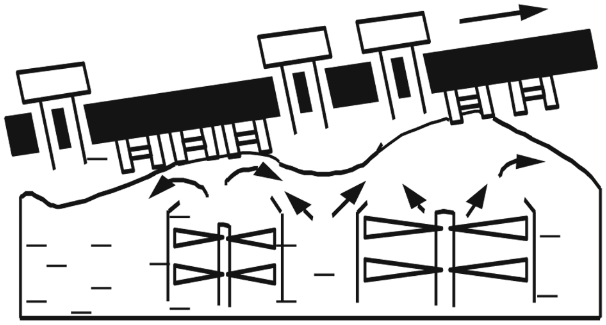


Fig. 25. Double wave soldering.

Fig. 26. Installation for double wave soldering in a protective environment.

Wave soldering systems employ both mechanical and electromagnetic flux applicators. The mechanical flux applicator operates based on the following principle (Fig. 27). Molten solder is continuously pumped into a closed chamber *1*, fitted with nozzle *2*, by a propeller mounted on shaft *5* connected to an electric motor via a V-belt drive. PCB *4* enters the solder wave at an angle α. The height of the solder wave crest *3* is adjusted by varying the speed of the dc motor through changes in the supply voltage using a variable autotransformer. While this design is the simplest, its drawback lies in the presence of rotating components in the molten solder. This necessitates additional

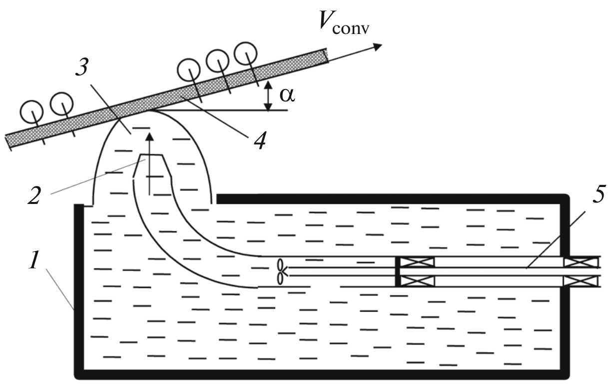


Fig. 27. Mechanical flux applicator.

motor engagement safeguards when the solder is not molten.

The principle of operation of electromagnetic flux applicators involves the interaction between an electrical current passing through the solder and an external magnetic field. This interaction induces electromagnetic (ponderomotive) forces in the liquid solder, directed perpendicular to the current and field vectors, causing the solder to move; $F_{\text{em}} = \vec{I} \times \vec{B}$.

Induction single-phase electromagnetic flux applicators have gained greater popularity, featuring specially profiled bath and a portion of the molten solder as a conductor to induce electric currents within it (Fig. 28a). Inside bath *1*, filled with liquid solder, chambers *2* and *3* are installed, within which the poles of electromagnet *4* are placed, connected to an ac power source. The chambers are surrounded by solder, forming two short-circuited coils with current around the poles of the electromagnet. Passing current through the coil induces an electric current in the solder, causing the molten solder to move upward, forming a solder jet with a width of no more than 100 mm.

The two-circuit electromagnetic flux applicator (Fig. 28b) consists of a W-shaped magnetic core *8*, with bath *5* positioned between the outer poles *2* and *4*, filled with solder. The central, shorter pole *3* is in contact with the bottom of the bath, surrounded by solder from all sides, forming a secondary short-circuited coil. Pole *1* is wound with an induction heating coil *6*, while pole *7* is wound with a flux applicator coil *8*. When both coils are energized with alternating current, a varying magnetic field is generated in the gap between poles *3* and *7*, inducing a current in the secondary liquid-metal coil. Their interaction results in that the solder is propelled upward. To achieve maximum propulsion force, the phase of the voltage supply to coil *8* is adjusted to match the phase of the induced current in the working gap. Heating and flux applicator modes are controlled separately, allowing for the adjustment of the current strength ratio between the coils generating the magnetic field and the induced current in the molten solder. The same hydraulic head of solder can be achieved with high magnetic field induction and low current, or vice versa. The advantages of electromagnetic flux applicators include

– Additional heating of the solder in the fluxing zone due to the induced electrical currents;

– Direct movement of the molten solder within the working channel by electromagnetic forces, reducing solder oxidation;

– Absence of moving parts in the solder;

– Easy adjustment of the wave height.

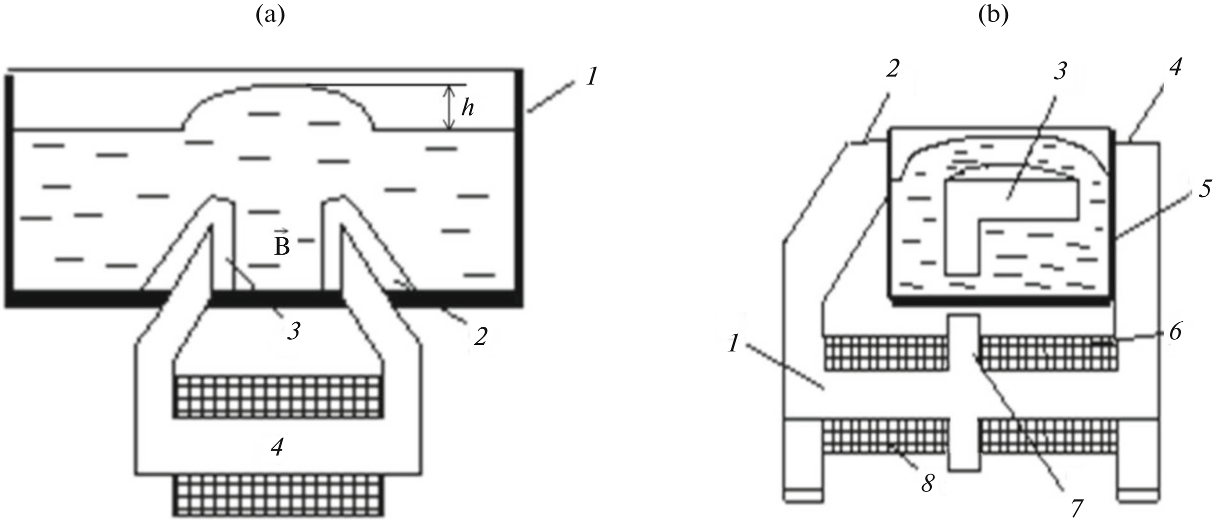

(a) (b)

Fig. 28. Electromagnetic flux applicators: (a) single-phase and (b) two-circuit.

Electromagnetic flux applicators enable the creation of a dynamic jet wave, ranging from 5 to 25 mm in height, with conveyor speeds of up to 3 m/min.

Reduction in defectiveness and ensuring a high percentage of acceptable electronic modules (up to 90% or higher) is achieved through the computerization of the wave soldering process. To implement computer control, it is necessary to set a matrix of parameters for each electronic assembly, including content, type of printed circuit board, length of component leads, conveyor velocity and width, board preheating temperature, flux density, soldering temperature, and others. Computerization ensures the stability of soldered joints' quality in mass production and increases inspection speed tenfold.

5. SOLDERING WITH SOLDERING IRONS AND SOLDERING STATIONS

In small-batch, multi-item manufacturing, various soldering iron and soldering station designs are widely used for forming assembly connections. In a soldering iron, heat transfer is facilitated by the thermal conductivity of the tip, which acts as a heat accumulator for the heat generated by the heating element. In a steady-state mode, the amount of heat accumulated in the copper rod depends on the power of the heater.

Temperature stabilization of the soldering iron tip is achieved through various methods:

– Thyristor temperature controllers, consisting of a temperature sensor mounted in the soldering tip at a distance of 30–40 mm from the working end and a control circuit. The temperature regulation accuracy at the solder joint reaches ±2°C, but at the working end of the tip, it is ±5°C due to the inertia of the thermal field;

– Heating with a variable electrical resistance element dependent on temperature. For example, in Philips soldering irons, the heating element consists of lead and barium agglomerate, the resistance of which increases by hundreds of times when heated above the Curie point, causing the current to decrease and the soldering iron to cool down, and after cooling below the Curie point, the process reverses.

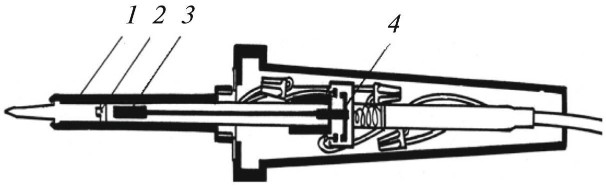


Fig. 29. Weller soldering iron with temperature stabilization: (*1*) heater, (*2*) temperature sensor, (*3*) permanent magnet, and (*4*) switch.

– Using a magnetic element (Fig. 29), which changes its properties when heated above the Curie point, as in Weller soldering irons (United States), resulting in the disconnection of the heater.

Soldering iron tips are characterized by the following geometric parameters: length, diameter, shape of the tip bend, and shape of the tip end. The length of the tip depends on the spatial arrangement of the joints and can range from 10 mm (microsoldering irons) to 300 mm (soldering irons for through-hole mounting). The diameter of the tip should be 5–15 times larger than the diameter of the conductor. A range of preferred diameters for soldering irons is adopted: 0.5, 0.8, 1.5, 3, 5, 8, and 10 mm [11].

The shape of the tip bend is selected based on the depth of the assembly and the intensity of the thermal load, as well as the spatial arrangement of the joints (Table 2, Fig. 30). The shape of the soldering iron tip end depends on the mounting density, size of the contact pads, and intensity of the thermal load (Table 3, Fig. 31).

In standardizing soldering iron tips, the following three-digit designations have been introduced: the first digit determines the diameter of the tip, the second (a letter) indicates the angle of the tip bend, and the last (a number) represents the tip shape. For example, 8B6, and so on.

The erosion resistance of a soldering iron tip determines its durability. A standard copper tip, due to intense dissolution in solder, loses its shape after about 1000 soldering operations and requires reshaping. To protect the tip, electroplated nickel with a thickness of 90–100 μm is applied, which roughly doubles the tip's service life. A promising solution to this problem is the

Table 2. Unified series of soldering iron tip bending

Iron tip index	Bend angle, deg	Application characteristics		
		mounting depth	load intensity	connection arrangement
A	0	Large	Any	Various types
B	90	Medium	Medium	Same types
C	120	Small	Medium	Variety of spatial positions
D	135	Small	High	

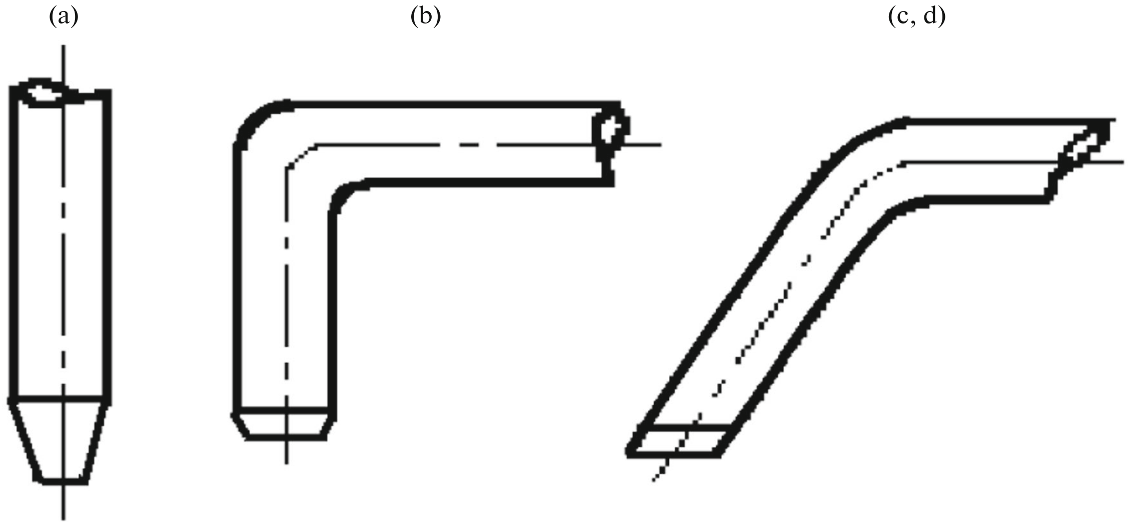


Fig. 30. Soldering iron tip shapes.

use of powder metallurgy copper–tungsten alloys. The increased thermal and wear resistance of tungsten is effectively combined with the good thermal conductivity of copper, while the porosity of the material improves solder wetting on the tip.

The WC100 Weller cordless soldering iron, designed for repair and assembly work, features built-in illumination of the soldering area, three interchangeable tips with diameters of 0.8, 1.5, and 2.5 mm, and a length of 63 mm. The tip heating time to 270°C is 6 s, and it operates for approximately 10 h with a cadmium battery.

Some companies produce various modifications of soldering stations, consisting of a stabilized power supply unit, a soldering iron with a set of interchangeable tips, and a vacuum solder fume extractor. Weller, for instance, manufactures soldering stations ranging from inexpensive models like the WESD51D (Fig. 32a) with a power of 50 W, which maintains the soldering iron temperature in the range of 240 to 450°C with an accuracy of 5°C, to complex soldering and repair centers with a wide range of tools. For repair work, cordless soldering irons powered by batteries are proposed (Fig. 32b).

Group soldering irons, which ensure simultaneous heating of leads from two (Fig. 33a) or four sides of the package and capture of the removed component, are more efficient.

In 1930, American engineer Carl Weller invented a new concept for soldering tools—a soldering gun. In this tool, the heating element and soldering tip are combined and consist of a specially shaped copper conductor, with maximum resistance concentrated at the wedge-shaped tip. This conductor is connected through a low-voltage secondary transformer, housed in a pistol-shaped plastic casing (Fig. 33b). The trigger activates or deactivates the gun and sometimes selects one of two working temperatures. The advantages of a soldering gun include rapid heating and cooling, a small and maneuverable tip, an inexpensive heating element, and the ability to control temperature with the trigger. However, it has disadvantages such as large

Table 3. Unified series of soldering iron tip sharpening

Sharpening no.	Iron tip configuration	L, mm	Application characteristics		
			mounting density	size of contact pads	heat load intensity
1	Two working planes	2	High	Small	Low
2	″	4	High	Medium	Medium
3	″	6	Medium	Large	High
4	One work plane	5	High	Medium	Medium
5	Three working planes	3	Medium	Medium	Medium
6	Increased surface	Up to 1	High	Small	Medium

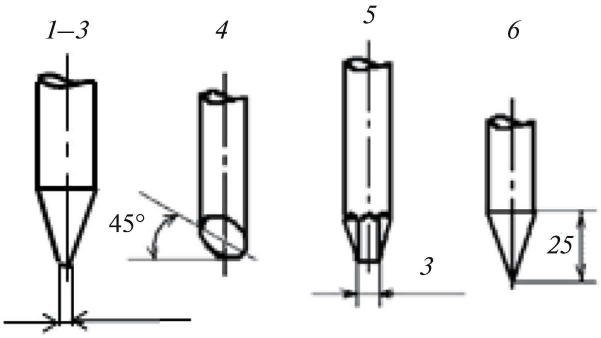


Fig. 31. Shapes of unified soldering iron tip sharpening.

mass and volume, significant current flowing through the tip, the need to work with a small tip at high temperatures to compensate for heat deficiency, and the presence of extensive magnetic fields.

In 1959, Carl Weller founded Weller Tools in Besigheim, Germany, which has since served not only as a manufacturing site but also as the engineering and logistics center for the company. The Weller Tools Company is known for producing high-quality soldering equipment.

The Ungar 6760 soldering gun features a rigidly grounded insulated tip to protect sensitive integrated circuits. Solid-state components replace the heavy transformer that generates magnetic fields, bringing the weight of the soldering gun down to 140 g. Instant selection between two temperatures, 500 or 900F, is achieved with a switch separated from the trigger.

The Model 450 All Gun from Wen is a temperature-controlled soldering gun equipped with three rigid interchangeable tips: a pencil tip with a power range of 25–100 W for printed circuit boards, a 100–200-W tip for internal device assembly, and a 200–450-W tip for soldering seams on embedded solder joints. The soldering tips of the high-powered guns, weighing 200 g, feature a special coating to guarantee more than 30000 soldered connections.

The IR-D3 Discovery repair system eliminates the need for tools or gas, offers precise regulation, is modular and upgradable, and ensures 100% yield in SMD soldering and repair without complications. It provides a high level of profiling and process control necessary for the efficient treatment of components, including SMD, BGA, CSP, QFN, and Flip Chip, with lead-free applications (Fig. 34). A precision vacuum chip placer ensures accurate positioning, while real-time monitoring controls the heating of microchips. The software enables setting any temperature profile with temperature control at eight points. To ensure uniform heating of the board, the lower heater has been enlarged to 300 × 450 mm. The soldering and repair center is equipped with a personal computer for process control, featuring a 750-W lower heater and a 150-W upper focused IR heater mounted on a stand.

The upper heater can accommodate various interchangeable lenses, ensuring the focus of the IR radiation on a spot ranging from 4 to 70 mm in diameter.

A NeoTerm multichannel soldering station (Fig. 35) from Magistr (Russia) is housed in a compact vertically oriented enclosure and offers the capability to control three soldering tools simultaneously. Each tool maintains a set temperature and is consistently ready for operation [13].

The control unit of the soldering station comprises a multichannel digital temperature controller, which measures the temperature of the soldering iron for each tool and supplies the necessary amount of energy to the tool's heater to maintain the set temperature. Each soldering tool has its memory for settings and a digital communication channel with the soldering station, allowing all settings to be stored. Using buttons on the front panel, the operator selects the desired tool and adjusts its parameters.

Each soldering iron handle is equipped with a motion sensor to transition it into an energy-saving


(a) (b)

Fig. 32. (a) Soldering station and (b) work with cordless soldering iron.

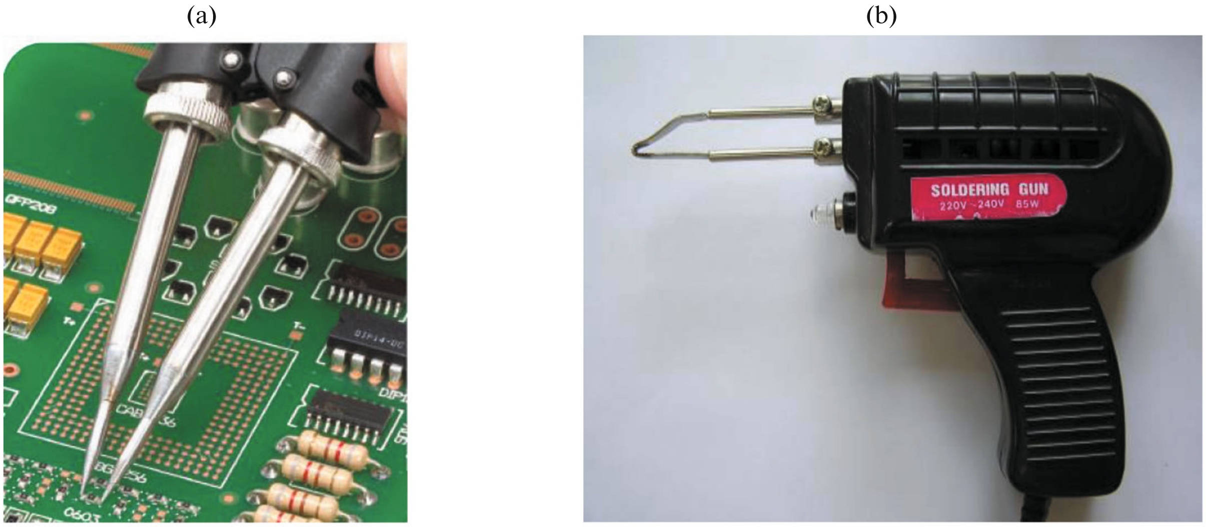


Fig. 33. (a) Group soldering iron and (b) soldering gun.

mode when not in use. A powerful heater, along with a temperature sensor, is housed inside the hollow soldering tip directly at the working end, ensuring minimal thermal inertia and achieving a heating rate of over 100°C/s at 90-W power. The temperature maintenance accuracy is within 2°C.

Smart Heat technology, a highly effective solution patented by OK International, involves the use of induction heating in soldering irons. The method is based on heating the soldering iron tip with a variable magnetic field. The tip itself is made of copper with a ferromagnetic coating on its tail section, which also serves as the core of the coil generating a constantly alternating magnetic field (Fig. 36). The tip is heated by induced surface currents. At the Curie point temperature, the ferromagnetic material loses its magnetic properties, and heating ceases, stabilizing the temperature.

Upon contact with the board, the temperature of the tip drops, and the magnetic properties of the material are instantly restored, causing the tip to absorb once again energy from the magnetic field, aiming to maintain the temperature at the Curie point. The more thermally conductive the joint being soldered, the more energy is absorbed from the field.

Thus, the induction soldering iron “adjusts” the required power for heating each contact based on its thermal conductivity. A miniature tool with an induction heater of only 35 W operates on a multilayered board much like some classic soldering irons with twice the power.

Fig. 34. IR-D3 Discovery soldering and repair center.

Fig. 35. NeoTerm-3T soldering station.

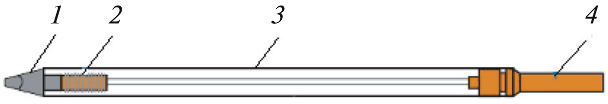


Fig. 36. Induction soldering iron: (*1*) tip, (*2*) induction heater winding, (*3*) shielding casing, and (*4*) connector.

The temperature cycles of a conventional soldering iron and an induction soldering station are shown in Fig. 37. The tests were conducted using a printed circuit board with solder joint dimensions of 1.6 × 5.0 mm, with soldering performed every 3 s [14].

The main advantages of induction soldering irons are as follows:

- Ability to adjust the desired temperature of the tip (by selecting a material with the appropriate Curie temperature);
- Low power consumption (heating occurs only in the surface skin layer of the tip, rather than the entire volume);
- Uniform heating of the tip and absence of temperature inertia (due to the lack of a heating electrode; the surface layer of the tip itself acts as the heater);
- Ease of tip replacement in case of damage (due to the absence of high requirements for contact with the inductive coil).

Mass-produced induction soldering stations from Quick (China) and OK International (United States) convert the network voltage into rectangular voltage with an amplitude of 36 V and a frequency of 400 kHz. This voltage is supplied to the exciting coil, which has minimal active resistance (no more than 1.3 Ω) and significant reactive resistance (not less than 50 mH). Moreover, the inductance of the coil without the soldering tip is 100 times less. Under these conditions, approximately 80–85% of the power transmitted from the soldering station is delivered to the soldering tip itself, which is connected as a transformer with a short-circuited secondary coil. The remaining 15–20% of the power heats the exciting coil, located outside the soldering tip, thereby conductively heating the tip [15].

Quick-203 soldering stations with power 60 and 90 W heat the soldering tip to a temperature of 300°C in 25–35 s and have a temperature range from 200 to 420°C. Quick-301 and Quick-303 stations are used for soldering with lead-free solder. These 80-W stations have a thermocouple located on the soldering tip and are equipped with a microprocessor temperature controller.

The PS-800 soldering station from OK International (Fig. 38), with a power of 50 W, ensures the same heat transfer as a 90-W soldering iron with a ceramic heater.

6. DISASSEMBLY OF ELECTRONIC COMPONENTS

Soldering irons with a system for solder removal from plated holes have been developed to disassemble electronic components from printed circuit boards (Fig. 39). Equipped with interchangeable tips and an internal heater, these soldering irons ensure rapid heating with relatively low power consumption (up to 50 W). At the output end of the nozzle, there is an injection nozzle for air pressure discharge, connected by a flexible hose to a compressed air supply valve mounted on a pedal. Through a voltage regulator, the soldering iron heater is connected to the mains at 36 V. The tip is positioned at the desoldering point on the board so that its axis is perpendicular to the board's plane [16].

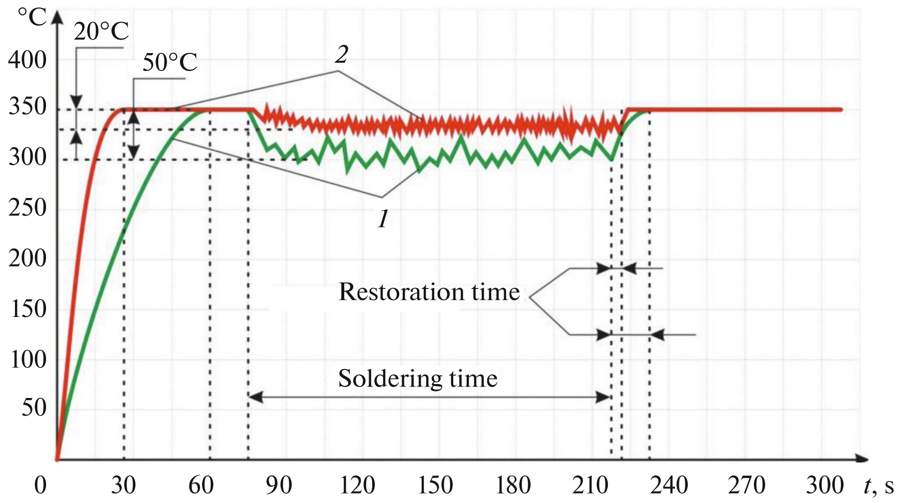


Fig. 37. Temperature cycles of (*1*) conventional and (*2*) induction soldering iron.

Fig. 38. PS-800 induction soldering station.

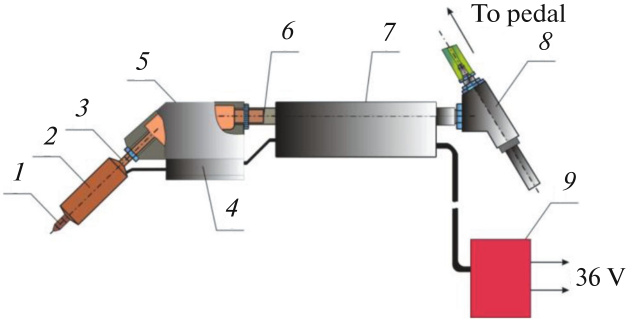


Fig. 39. Soldering iron for electronic component removal: (*1*) interchangeable tip, (*2*) heater, (*3*) hollow rod, (*4*) connector block, (*5*) solder collector, (*6*) nozzle, (*7*) handle, (*8*) injection nozzle, and (*9*) voltage regulator.

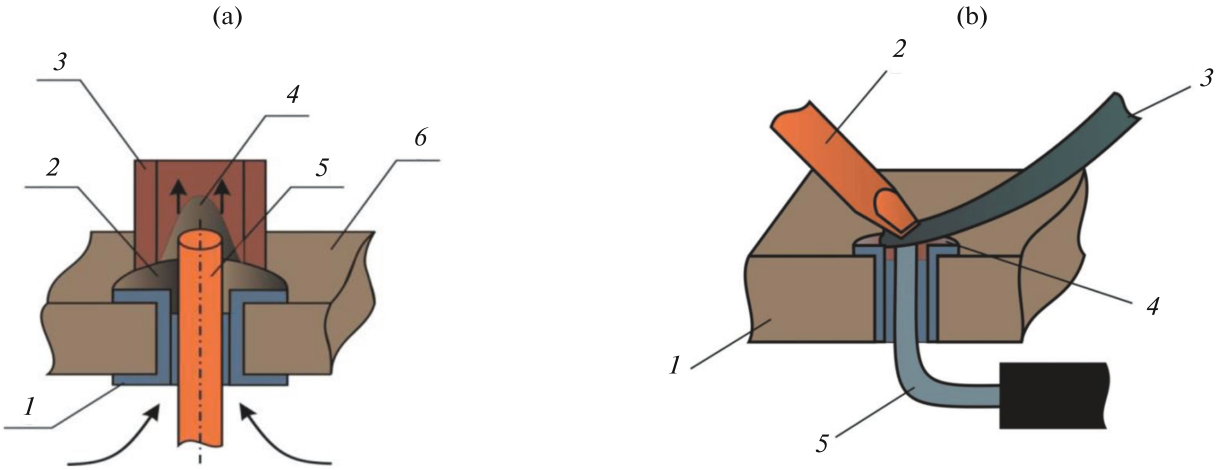


Fig. 40. Removal of solder (a) by vacuum desoldering: (*1*) metalized hole, (*2*) solder, (*3*) soldering iron tip, (*4*) solder suction, (*5*) component lead, and (*6*) printed circuit board and (b) by a desoldering wick: (*1*) printed circuit board, (*2*) soldering iron tip, (*3*) wick, (*4*) contact pad, and (*5*) component lead.

After melting the solder, pressing the foot pedal supplies compressed air to the injection nozzle, creating a vacuum that removes the solder from the desoldering point. Once the pedal is released, the airflow stops. The solder accumulates in the soldering iron's collector chambers, from where it is subsequently removed. The desoldering time for a single joint is 1–2 s.

When a large amount of solder needs to be removed, a vacuum desoldering tool is used, as illustrated in Fig. 40a. The main drawback of this method is the requirement for direct physical contact with the contact pad surface, leading to conductive heat transfer to the board and its significant heating.

Another method for removing solder from the surface of a printed circuit board is by using a desoldering wick (Fig. 40b), which is a braided wire placed between the solder on the contact pad and the soldering iron tip. When the soldering iron is heated, the solder melts and is drawn into the desoldering wick due to capillary action, which is greater when there are more gaps between the wire strands of the wick. Good wetting and solderability of the wire coating material are essential here. To increase the number of capillaries, the wick should consist of multiple thin wires made of pure copper.

The primary advantage is that there is no overheating of the printed circuit board at the soldering iron contact points, even though temperatures during desoldering may reach 300–400°C. The excess heat is dissipated into melting the solder, which is instantly absorbed by the desoldering wick.

However, the drawback of this method is the high cost of desoldering wick material, the need for additional protection measures (fluxing), the complexity of cleaning the wick from solder residue, and its inability to be used for cleaning through-hole vias, as the capillary effect is more pronounced in them.

Fig. 41. Equipment for component removal: (a) vacuum tweezers, (b) soldering station, (c) gas torch, (d) heat gun with two nozzles, (e) tweezers, and (f) heat gun nozzles.

A variety of specialized fixtures and tools are used for the removal of electronic components of various designs, differing in size and number of leads (Fig. 41).

The third generation of IR rework stations, such as the ERSA IR/PL 650, is specifically designed for lead-free technology, complex components (ranging from 1 × 1 to 60 × 60 mm), and large PCB sizes (460 × 560 mm). The process of mounting and removing microchips is carried out in a semiautomatic mode, ensuring high precision (up to 0.01 mm). The repair center comprises contact-type tools with microprocessor-controlled temperature regulation and infrared emitters (Fig. 42). The infrared section of the station includes two emitters: upper and lower. The lower IR emitter (350 × 450 mm) with a power of 3.2 kW is used to preheat a large area of the printed circuit board to 120–150°C to decrease temperature differentials and shorten the overall soldering or desoldering process. The upper IR emitter (IR gun) creates a heating zone measuring 60 × 120 mm. Infrared radiation is emitted at wavelengths of 2–8 μm, which are optimal in terms of the ratio of reflected to absorbed thermal energy. The lower IR emitter is utilized to accelerate soldering or desoldering, preheat PCBs to eliminate the “popcorn effect,” and prevent microcracks in ceramic chip components.

A laser LED pointer is used to illuminate the center point of the working area, indicating where components should be placed for soldering or desoldering. These components include microchips in BGA, CSP, PGA, SOIC, QFP, and PLCC packages, as well as connectors, shielding components, and complex-profile elements. Microprocessor control and low-inertia heaters ensure maximum thermal stability. The temperature range can be adjusted from 50 to 450°C. Service functions include automatic tool recognition, temperature calibration for specific nozzles, memory for 9 modes, and selection of temperature regulation profiles (“soft” for particularly sensitive components

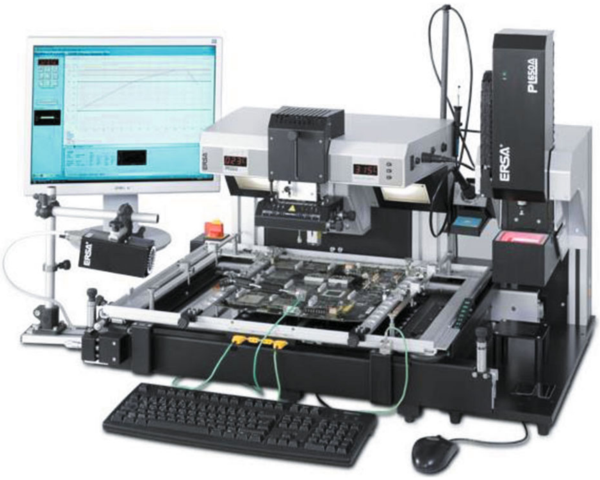


Fig. 42. IR/PL 650 universal soldering and repair station.

or “hard” for high-speed soldering of bulky contact connections in products).

7. METHODS OF CLEANING FLUX RESIDUES

Cleaning electronic modules after soldering is a critical final operation responsible for ensuring the complete removal of all contaminants associated with the production of printed circuit boards, storage, assembly, and soldering. Therefore, cleaning should remove contaminants of all types of electrolyte salts, etching solutions, fluxes, flux activators, fingerprints, dust, and abrasive particles.

After soldering, there remains some amount of flux and decomposition products on the board. They can cause corrosion, degrade the electrical parameters of the circuit, and deteriorate solder joints. The need for cleaning the board after soldering is determined by the required reliability of the equipment, its operating conditions, and the purpose of the product. When using protective coatings, cleaning is mandatory in all cases. Various solvents and compositions, including water, are used for washing the boards. Cleaning agents must be able to dissolve both the binding agent and the basic material of the flux. Based on the nature of the contaminants and their relationship with the surface, the following main types of contaminants are distinguished:

Inorganic:

– Mechanically weakly bound to the surface (dust, shavings, metallic and nonmetallic chips, soot, etc.);

– Mechanically embedded in the surface (abrasive grains, mineral or metallic particles);

– Deposited on the surface (salt crusts, scale, etc.).

Organic:

– Mechanically weakly bound to the surface (dust, plastic chips and shavings, soot, coal, coke);

– Possessing a low degree of adhesion to the surface (greasy and oily films, lubricants, grinding, polishing, and lapping pastes);

– Firmly adhered to the surface (resin, varnish, glue, paint, etc.).

During chemical cleaning, where contaminants are dissolved by a reagent, direct contact between the reagent and the contaminant occurs. As the chemical cleaner dissolves the contaminants, a saturated layer develops at the interface, halting the cleansing action (Fig. 43a). Ultrasonic cavitation and microbubble explosions effectively displace the saturated layer, allowing a fresh portion of a chemical reagent to come into contact with the contaminant. This is particularly beneficial when cleaning irregular surfaces or internal voids (Fig. 43b).

Some types of contaminants consist of insoluble particles held on the surface by ionic forces. To remove these particles, it is sufficient to displace them to break the attractive forces with the surface. This is facilitated by cavitation bubbles (Fig. 43c). The ultrasonic effect

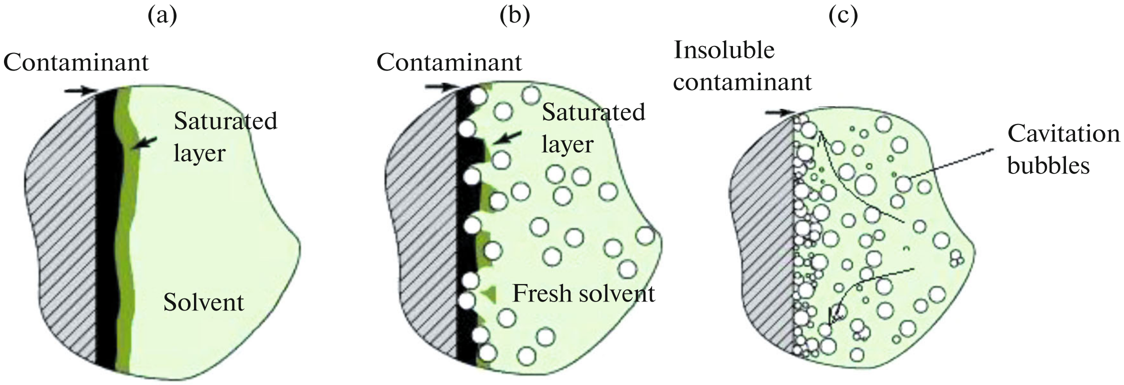


Fig. 43. Surface cleaning of electronic assemblies: (a) chemical cleaning, (b) ultrasonic cleaning, and (c) ultrasonic cleaning of insoluble contaminants.

essentially creates mechanical micromixing, which more effectively removes soluble and insoluble contaminants.

Poor cleaning of products leads to a decrease in insulation resistance during their operation or storage and physical destruction of conductors due to corrosion, and the corrosion products themselves can lead to current leakage, disruption of moisture protection coatings, etc. All of these factors violate the reliability of electronic products. Analysis of the causes of failures of electronic products shows that a quarter of them are attributed to poor surface cleaning quality [18].

The cleaning of electronic modules on printed circuit boards involves a rather complex chemical process, which can lead to various issues such as incomplete removal of flux residues, removal of component markings, white residues, damage to electronic components, and excess moisture on the boards after drying. In surface-mount assembly, it is necessary to clean stencils since their cleanliness is a critical factor for the quality of stencil printing. Contaminated apertures lead to serious printing errors, which directly affect the assembly quality. Modern requirements for high-quality stencil printing are associated with the use of packages such as BGA, QFP, CSP, and others with a large number of pins and small pitches. The challenges of improving post-soldering cleaning quality are associated with several factors:

– Increased assembly density due to the transition to surface mounting with a pitch of less than 1.27 mm;

– Use of solder pastes containing up to 12 different organic compounds;

– Small gaps between components and the board intensify the capillary effect and flux entrapment in the gaps;

– Transition to lead-free solders results in increased soldering temperatures, leading to flux carbonization and reduced solubility.

Cleaning solutions must meet the following requirements:

– Have a high surface tension to penetrate gaps effectively;

– Possess high activity against contaminants;

– Remove both organic and inorganic polar contaminants.

In terms of cleansing ability and chemical composition, surfactants can be classified into two main categories: (1) hydrophobic, which are immiscible with water and excel in removing organic contaminants such as resins and fats, and to a lesser extent, polar impurities like organic solvents; and (2) hydrophilic, which rely on water-based solutions of surfactants and Micro Phase Cleaning (MPC) phases for the removal of polar impurities.

The removal of residues of rosin fluxes is accomplished using an alcohol–benzene mixture, trichloroethylene, and carbon tetrachloride. The rinsing process in the alcohol–benzene mixture occurs in three baths with the application of solution agitation through bubbling, vibrations, and other means. The rinsing time typically ranges from 10 to 15 min per board, with simultaneous rinsing of 5 to 10 boards. The effective action period of the solution averages 3 days, after which disposal is necessary. The alcohol–benzene mixture poorly removes ionic water-soluble components, leaving a white deposit on the surface and exhibiting high toxicity and flammability.

Cleaning of boards after soldering with water-soluble fluxes is carried out using hot water (50–60°C) with the addition of surfactants. The cleaning process follows the scheme: cleaning in the washing solution for 10 min at 60°C, solution draining for 0.5 min, rinsing in water for 5 min at 60°C, rinsing in deionized water for 5 min at 25°C, preliminary drying 30 min at 60°C, final drying for 180 min at 25°C. This technology has enabled the elimination of the alcohol–benzene mixture and prevented environmental contamination by organic solvent vapors. Aqueous surfactant solutions effectively dissolve contaminants from the surface of boards during jet and ultrasonic cleaning. However, surfactants gradually deplete and form tight bonds with the particles of contamination, resulting in a white deposit on the surface.

MPC technology uses flushing fluids with microphases to detach contaminants from surfaces and transfer them into the aqueous environment without forming rigid bonds. Subsequently, contaminants are removed from the washing solution using mechanical filters. The flushing fluid is continuously regenerated and does not deplete over time. VIGON flushing fluid, employing the MPC technology developed by Zestron, boasts a lifespan of up to 180 cycles and ensures safety in application [19].

An alternative to organic solvents and refrigerants is ultrasonic cleaning in aqueous solutions of surfactants. The action of ultrasonic fields on liquid media induces cavitation processes therein, as well as macro- and microflows within the volume of the liquid adjacent to the radiating surface of the bath. The collapse of cavitation gas voids is accompanied by the formation of shock microjets, with pressures reaching $(1–5) \times 10^8$ Pa. Such microimpacts not only disrupt oxide films and contaminants on the treated surface of products but also, to some extent, alter the surface morphology. The emerging micro- and macroflows contribute to the removal of contaminants and accelerate the cleaning process of microtextured surfaces. Cavitation-induced dynamic and thermal effects intensify the removal of contaminants from the surfaces of parts and products under the influence of ultrasonic fields.

Fig. 44. Arrangement of ultrasound transducers on a vibration panel.

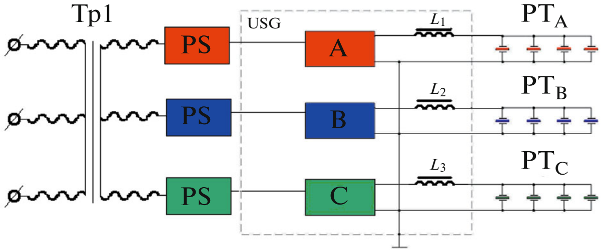


Fig. 45. Modular ultrasound generator (USG): A, B, C, channels; L_1, L_2, L_3, matching chokes; PT_A–PT_C, piezoelectric transducers; PS, power supply;

Using operating frequencies in the range of 80–120 kHz ensures nondestructive cleaning and removal of contaminants sized up to 1 μm from microtextured surfaces.

The primary advantages of ultrasonic cleaning over other methods of contaminant removal include high productivity coupled with excellent product cleaning quality, effectively eliminating any surface films. The most efficient approach involves batch processing of small items arranged in cassettes or baskets. To achieve high-quality cleaning, it is essential to generate directed acoustic flows and ensure uniform distribution of ultrasonic field intensity throughout the liquid volume.

In commonly used designs, the bottom of the bath is typically comprised of an emitting diaphragm of a magnetostrictive transducer. The distribution of acoustic pressure generated by such systems is highly uneven, up to 50%. At the center of the bath, above the diaphragm, the pressure reaches its maximum value and gradually decreases towards the edge of the membrane.

During ultrasonic cleaning of electronic modules, a primary requirement for ultrasonic technological systems is the high uniformity of vibration impact on the products. Therefore, various numbers of batch piezoelectric transducers (BPTs) with a power of 50–100 W are used to excite ultrasonic vibrations, mounted on the side walls and bottom of the bath in a specific order, with parallel connection to the generator. In this case, the efficiency and stability of the transducers' operation depend on the bandwidth, as the frequency ranges of individual transducers largely overlap, allowing compensation for the variation in their resonant frequencies.

In comparison to the linear arrangement of BPTs, the modular system of distributed BPTs installed in a staggered pattern (Fig. 44) shows greater promise. Such an arrangement of transducers creates a uniform ultrasound field over the area when excited in three phases, owing to the superposition of waves emitted by BPTs connected to different channels of the US generator. The distance between the centers of transducers in the group is a multiple of the wavelength λ of ultrasonic waves propagating in the liquid [20].

The output signal of the channel consists of the sum of three harmonic oscillations with the fundamental frequency ω and side frequencies (ω + 100) Hz and (ω – 100) Hz. Since the autogenerators are powered by pulsating voltage, periodic fluctuations in frequency contribute to the averaging of the near field due to the periodic variation of the interference pattern. The total input impedances of the transducer groups, together with compensating inductances, form resonant circuits that determine the operating frequency of the generator channels. All changes in technological conditions (temperature and composition of the solution, insertion of a cassette with parts into the bath) lead to a change in the total input impedance of the transducer, and thus to a change in the frequency of the generated oscillations.

The rectifiers of the power supply units of the channels are connected via step-down transformers to the corresponding phases of the three-phase alternating current network, resulting in signals at the output of the channels being phase-shifted by 120°, and groups of ultrasound oscillation pulses shifted by the same angle are supplied to the transducers (Fig. 45).

The region of maximum acoustic pressure, corresponding to the maximum voltage at the transducer, sequentially moves from transducer A to B and from B to C (or vice versa when rephasing channels) in each group.

As a result, directed fluid flows arise from the region of higher acoustic pressure to the region of lower pressure. Since the movement of regions occurs at a relatively low frequency (100 Hz), vortex macroflows develop in the liquid medium with a certain viscosity, alongside microflows arising in the viscous boundary layer near obstacles, intensifying the processes of contaminant dissolution.

Elmasonic ultrasonic baths (Fig. 46a) operate at a frequency of 37 kHz and have a volume ranging from

Fig. 46. Ultrasonic cleaning baths (a) Elmasonic and (b) Sapfir.

82 to 180 L, with liquid heating from 30 to 80°C, an electronic timer, oscillation of the ultrasonic field, and emitter power ranging from 1.8 to 3.2 kW. Sapfir ultrasonic baths (Russia, Fig. 46b) operate at a frequency of 35 kHz with liquid heating up to 70°C, generator power of 100 W, and two emitters.

Some electronic components, e.g., quartz resonators, integrated circuits, semiconductor devices with wire assembly, etc., are sensitive to ultrasonic exposure. Megahertz quartz resonators are not damaged during ultrasonic cleaning, but clock quartzes may fail at an ultrasonic frequency of 35 kHz. Therefore, ultrasonic cleaning is typically performed at frequencies higher than 40 kHz. Electronic modules should be vertically positioned in the ultrasonic bath to avoid obstructing the passage of ultrasonic waves. The module basket should be placed in the bath on the legs at a height of 15–30 mm above the bottom of the bath. The highest ultrasonic efficiency is achieved in aqueous solutions at temperatures ranging from 40 to 75°C.

For cleaning electronic modules with integrated circuits in plastic enclosures, the following parameters are recommended: frequency range of 40–66 kHz, maximum ultrasonic power density of up to 30 W/L, and cleaning time of up to 10 min. Microprocessors integrated into ultrasonic baths ensure control over the temperature and operating time of the bath.

To ensure the suitability of electronic modules for ultrasonic cleaning, the IPC-TM-650 method no. 2.6.9.2 "Determination of Electronic Component Sensitivity to Ultrasonic Energy" is used. The resonant frequency of the wire Al and Au leads with a diameter of 30 μm and a length of 3.0 mm in integrated circuits is approximately 10 kHz and lower. Therefore, the lower the ultrasonic frequency, the more aggressive the cavitation effect [21]. To eliminate mechanical resonances in wire connections and enhance the uniformity of the ultrasonic field in the bath, a sweeping frequency mode is recommended. Ultrasonic cleaning is not recommended for quartz resonators.

Ultrasonic cleaning of electronic modules on printed circuit boards, according to the IPC-STD001E standard, is permissible under the following conditions [22]:

– Printed circuit boards without electronic components or boards containing only terminals or connectors;

– Printed circuit boards with electronic components, given that the manufacturer can documentarily confirm that the ultrasonic exposure does not deteriorate the mechanical and electrical characteristics of the product or components subjected to cleaning.

Ultrasonic cleaning of boards after soldering at a temperature of 60°C for 12 min at a frequency of 30 kHz, followed by rinsing for four cycles in deionized water, effectively removes all flux residues from solder pastes.

The ultrasonic mode settings are adjusted using the method of erosion destruction of aluminum foil at various distances from the emitter. The erosion activity is assessed based on the degree of foil destruction placed in the working chamber parallel to the surface of the emitter at distances of 5–10 mm from the emitter. After the tests, the foil is air-dried, the area of damage is determined capacitively, and the erosion activity is calculated as

$$I = \frac{C_0 - C_p}{C_p} \times 100\%, \tag{7}$$

where C_0 is the foil capacity before testing, and C_p is the foil capacity after ultrasonic exposure (Fig. 47).

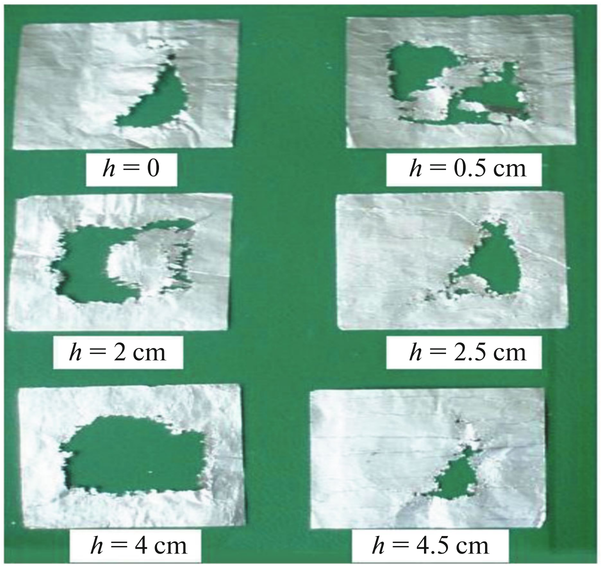


Fig. 47. Appearance of the foil after tests at different distances from the emitter.

The drawbacks of the method lie in the duration of measurements and the lack of continuous monitoring of the cavitation process. Spectral analysis of acoustic noise is used to assess cavitation activity since all other known methods for evaluating cavitation activity, such as erosion test, iodine test, and measurement of sonoluminescence intensity, have limited applications and do not allow for continuous monitoring during production. This limitation significantly restricts the possibilities of applying powerful ultrasonics in electronics technology. Cavitation noise is the most convenient for use as an indicator of cavitation activity, as the acoustic signal can be relatively easily converted into electrical signals [23].

To assess the intensity of cavitation pressure in liquid media, it has been proposed to measure the root-mean-square value of noise levels in the frequency band from the 20th to the 40th harmonic [24] using a cavitation meter consisting of a sensor, bandpass filter, quadratic detector, and recording device [25]. The cavitation meter (Fig. 48) measures cavitation pressures from 5 to 5×10^4 Pa in the frequency range of 18–60 kHz with an accuracy of ±10%. The pressure in the cavitation area is detected by a flat disk *1* with a size of 1 cm^2 connected to an elastic waveguide *2* with a piezoelectric transducer *3*. The electrical signal from the transducer is sent to amplifier *4*, located in the sensor housing, which serves to match it with the input of the measuring device. Attenuator *5* weakens the input signal from the sensor at high ultrasonic power. The bandpass filter *6*, designed according to the third-order Chebyshev circuit, isolates a portion of the signal spectrum characteristic of cavitation pulses. The signal then passes through the root-mean-square detector *8*, dc amplifier *9*, and is displayed on the meter. Source *10* powers the measuring instrument and the sensor. The instrument readings (Fig. 49a) are recorded after 1–2 s, when the cavitation process stabilizes.

To measure the characteristics of the noise spectrum and assess cavitation activity in powerful ultrasonic fields, a cavitation activity indicator has been developed at the Belarusian State University of Informatics and Radioelectronics (BSUIR). The principle of operation is based on the analysis and processing of the noise spectrum generated in liquid media under the action of powerful ultrasonic fields. The indicator consists of an electronic unit and a wideband sensor with a waveguide, designed to operate at high temperatures (Fig. 49b).

In addition to ultrasonics, liquid jets are widely used for mechanical activation during cleaning processes. The cleaning process typically involves several stages: jet cleaning using water-based or semi-aqueous liquids, rinsing in deionized water in two baths, and vacuum drying. In NC25 cleaning systems (France), convective drying with a cyclically created vacuum is used, allowing the drying temperature to be decreased to levels noncritical for the product [26].

SYSTRONIC Company (Germany), specializing in the production of industrial jet cleaning systems, offers solutions for cleaning printed circuit boards after soldering or stencil printing, stencils, squeegees, solder frames, pallets, filters for convection ovens, and

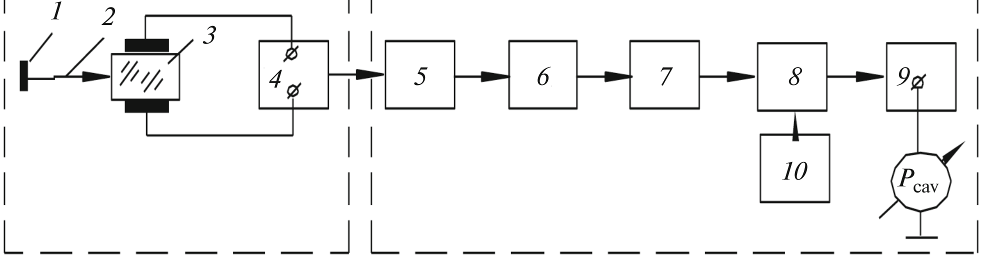
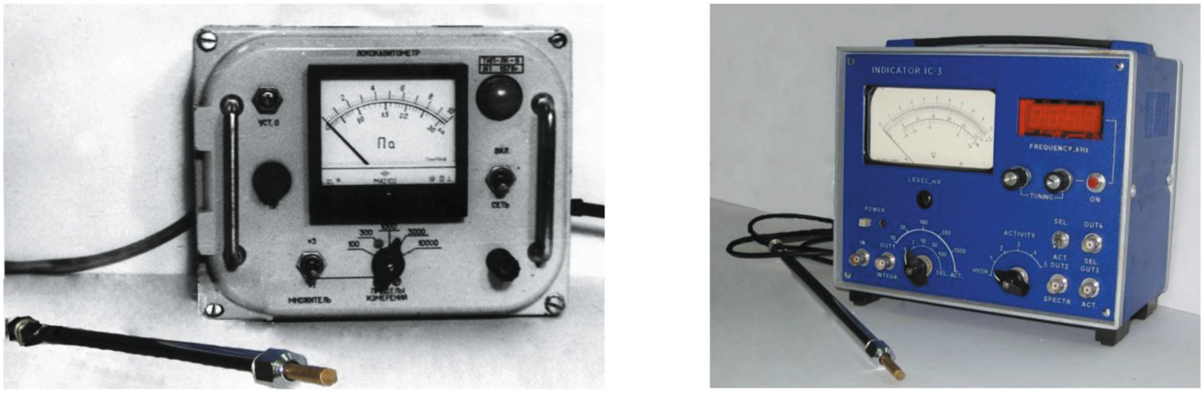


Fig. 48. Cavitation meter.



(a) (b)

Fig. 49. Appearance of (a) the cavitation meter and (b) the cavitation indicator.

(a) (b)

Fig. 50. Jet cleaning systems: (a) CL420 and (b) CL900.

more. The jet method ensures safe, nondamaging cleaning and enables the cleaning of electronic modules with sensitive components [27].

The CL420 jet cleaning system represents a versatile solution for high-tech cleaning needs. The parts to be cleaned are secured in special frames and loaded into the unit in a vertical position.

The cleaning process is carried out using two rotating nozzles and consists of several stages: washing with cleaning fluid, rinsing, and drying with hot air. The CL420 units feature a compact size and low energy consumption (Fig. 50a) [25].

The CL900 jet cleaning system enables high-quality cleaning of printed circuit boards from flux residues after soldering and other types of contaminants arising during the production and assembly of PCBs. The cleaning process consists of the following stages: washing with cleaning fluid, preliminary rinsing with water, final rinsing with deionized water with conductivity level control, and drying with hot air with filtered airflow. The patented design of the four-level spray system eliminates the formation of shadow zones on the cleaned boards, ensuring complete and consistent cleaning of all items placed in the basket. The large-

Table 4. Methods for controlling surface contamination

Control method	Sensitivity, μg/cm^2	Application area
Luminescence, by the film glow	8–10	Quality control of degreasing from mineral oils and rosin
Using phosphor	1	High-quality control of parts with a polished surface
Analysis of pollutant extract in organic solvents	0.2–0.3	Semiquantitative quality control of degreasing
Conductometry	0.1	Monitoring the processes of washing parts in water after chemical treatment operations
Photocalorimetry	0.02–0.05	Determination of ions S^{-2}, SO_4^{2-}, PO_4^{3-}, NO_3^-, etc.

volume working chamber and the unique two-level basket design enable simultaneous cleaning of 54 boards in one cycle. Thanks to its high productivity and reliable construction, the CL900 unit can be used in serial production conditions with round-the-clock operation (Fig. 50b).

Quality control of flux residue cleaning is carried out through visual inspection under a microscope at a magnification of (8–10)×, as well as through fluorescence or conductometric methods. The fluorescence method of control is based on the phenomenon of fluorescence emission of substances present in the composition of fluxes (rosin, salicylic acid, etc.). Sources of emission during board irradiation include lamps SVD-129A and PRK-5 with a UVFS-6 filter. The contaminants are detected by the visible fluorescence of residues on the surface of the board in a dark chamber: blue for rosin grade B and salicylic acid, yellow for rosin grade A. The method's accuracy is up to 1 × 10 g/cm^2 [1].

To achieve high-quality cleaning, it is necessary to control surface contaminants. Direct and indirect methods are applied to determine organic and inorganic surface contaminants. Direct methods involve identifying contaminants directly on the surface of the inspected items, while indirect methods are based on extracting contaminants with a solvent followed by analyzing the extracts using physicochemical or physical methods, which enables the detection of small amounts of surface contaminants (Table 4).

The conductometric method is based on measuring the resistance of distilled water before and after the controlled cleaning of the examined fluxes. Conductometric analysis is conducted to monitor the presence of flux residues by measuring the resistance of distilled water before and after the controlled cleaning of the examined fluxes. The cleaned electronic assembly is immersed in distilled water at a temperature of 20 ± 5°C and rinsed for 5 min. A sensor is submerged in a glass containing rinse water with a capacity of 500–800 cm^3, and the specific resistance of the water is measured using a conductometric concentrator meter, which should be no less than 20×10^3 Ω/cm^3 [1].

For rapid quality control of washing, a device is used to remove air from the liquid flow and preconcentrate mechanical impurities in a control flow, thereby enhancing the instrument's sensitivity to low levels of contaminants in the main liquid flow. The vortex method is the most reliable in operation, which forms the basis of the design of the separating apparatus—a hydrocyclone.

Automation of trichloroethylene control for the presence of fatty contaminants is achieved using an EF-3MA compact electronic fluorimeter, which features a glass flow-through cuvette integrated with a sampler connected to the analyzed instrument, enabling the measurement of fluorescence intensity. Residues of rosin flux on the board are determined using the Storch–Morawski reaction with a relative error not exceeding 10%.

The most promising methods for surface cleanliness and process media control rely on exploiting the differences in the physicochemical properties of clean and contaminated surfaces. One such method is tribometric analysis. The principle of operation of the corresponding device is based on measuring the level of ionic contamination, expressed in terms of the equivalent amount of sodium chloride.

Ionic contamination is measured by immersing the sample in a verification solution consisting of 2-propanol (50 or 75%) and deionized water. The dissolution of ion-containing substances changes the conductivity of the mixture; the measured value of this change is converted into the level of contamination, expressed in micrograms per square centimeter, in terms of NaCl equivalent.

To create a standard liquid, 2-propanol (analytical grade) undergoes purification by passing it through a column containing special resins until reaching the minimum value of electrical conductivity. The test assemblies are placed in a special tank, and under the action of the pumped liquid, residues of contamination are removed, and the level of ionic contamination is measured.

In the CM series devices by GEN3 (United Kingdom), measurement cells made of pure gold, ballistic

Fig. 51. Ion contamination control devices: (a) CM60 and (b) CM11.

amplifiers, and powerful pumping systems are utilized, ensuring the highest measurement accuracy of up to <0.005 mg/cm^2 [28].

The CM60 device (Fig. 51a), incorporating a virtual measurement cell (VMC), automatically calculates the area of the tested surface based on the volume of the displaced solution when the object is placed in the tank. It ensures a high level of measurement accuracy and demonstrates more quantitative analysis results compared to other methods. The graphical representation of the test results includes automatic contour detection of curves converted to NaCl equivalent (μg/cm^2). Contamination is measured over time, and the plotted curve is automatically extrapolated, enabling rapid data acquisition during testing.

The CM11 and CM12 devices (Fig. 51b) are tabletop models used for inspecting small electronic modules and printed circuit boards. Similar to the CM60, ion contamination is measured by immersing the sample in a test solution, where the dissolution of ion-containing substances leads to a change in its conductivity. Acceptable contamination levels depending on the equipment class, conforming to the international standard IPC-J-STD 00E, are listed in Table 5.

Table 5. Permissible levels of contamination

Class of electronic equipment	Permissible level of ionic contaminants, mg/cm^2	Permissible level of rosin residues, mg/cm^2
Household	Up to 1.56	Up to 200
Industrial	Up to 1.3	Up to 100
Special	Less than 1.0	Up to 40

FUNDING

This work was supported by ongoing institutional funding. No additional grants to carry out or direct this particular research were obtained.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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Translated by O. Zhukova