The joining of two spherical particles of nickel alloy powder under the action of laser irradiation, and the laser sintering of thin layers of poured powder were investigated. It was determined that powder particles experience surface melting under the action of laser heating, and join by a welding mechanism.

A number of papers have recently been published [1-4] on the study and development of a new powder metallurgy method — laser selective layer sintering. This method enables the production of articles of complicated shape, without use of traditional molding methods, by selective sintering under the action of a laser beam applied in succession to the layers of powder.

It is mentioned by the authors of the cited papers (see, for example, [4]), that the initial attempts to laser sinter one-component metallic powders (lead, zinc, tin) did not yield the expected results. The reason was that under the action of intense short-duration laser irradiation the powder particles melted and collected into spherical drops. In other words, the powder did not sinter, but simply remelted. Based on these results, it was concluded that laser sintering was not a promising method for one-component systems. Main attention was directed to the laser sintering of two-component systems, consisting of substances with very different melting points (temperatures of transition to the fluid state). These include metal—metal, ceramic—glass, ceramic—ceramic-polymer, metal—polymer, etc., systems. When these are laser sintered, the low-melting particles form a liquid phase which interconnects the particles of high-melting phase; that is, a mechanism similar to that of liquid-phase sintering is realized [5, 6].

However, as shown by our preliminary experimental results, laser sintering can be carried out as successfully for one-component as for two-component powders. As an example, Fig. 1a, shows specimens which were obtained by laser selective layer sintering of nickel alloy powder PG10N01 (the sintering regime is described in [7]). Structural studies showed that these specimens consist of particles of approximately the same size as in the original powder. Obvious particle coarsening, such as might be produced by melting and fusion, was not observed. Melting drops formed only when the powders were excessively overheated; for example, when the power of the laser beam was sharply increased. At low degrees of heating sintering did not occur at all, or else the contacts between powder particles were insufficiently welded. This suggests the existence of an optimal regime of laser treatment to obtain sintered particles in the powder body.

The present work was devoted to an experimental investigation of the process of interparticle welding in the sintering of one-component metallic powders under the action of laser irradiation. In the first series of experiments the sintering process was studied using the two-particle model. Grains of the previously mentioned nickel alloy powder were chosen for the investigation.

In designing the experiments we began with the idea, as in [4], that laser irradiation results in particle melting. However, we assumed that the particles experience only surface melting, and, consequently, they join primarily by the so-called welding mechanism* [8]. The experimental model for this process consisted of two spherical particles.

*According to [7], particles of the nickel alloy sinter by a solid-phase mechanism, which is obviously not true if possible melting is considered. It was assumed that the liquid phase sintering which usually occurs in two-phase systems is absent in this case.
Fig. 1. Specimens of multilayered articles (a) and external appearance of particles at various stages of joining (b-f). (a) Plane (total length 45 mm, width 4 mm, height 3 mm) and rod (4 mm diameter, 12 mm high); (b-f) diameter of particles ~1 mm; $P = 95$ (a), 290 W/cm$^2$ (b-f); $t = 40$ (b), 0.5 (c), 1 (d), 1.5 (e), and 2 sec (f).

Fig. 2. Time dependence of the diameters of the contact neck $d$, of the contact chord $D$, and the distance between particle centers $l$. $P = 95$ (a), 115 W/cm$^2$ (b).

Particles about 1 mm in diameter were obtained by laser melting of several smaller particles of the original powder. The spherical particles were situated pairwise on a quartz glass substrate, brought into contact with each other, and subjected to laser heating for a prescribed length of time. Each pair of particles was of the same size. The diameter of the parallel laser beam was about 5 mm, so that both particles situated at the center of the beam experienced the same amount of irradiation. A type LTN-103 continuous Nd:YAG laser was used in the experiments. The energy flux density was varied in different experiments.

The change in condition of the particles with time was followed using an optical microscope. Video recording of particle joining, with frame by frame review, made it possible to determine the time dependence of the process. Television images of the particles at a magnification of 100× were reproduced on transparent sheet screens, with whose aid the basic geometric parameters of the process were determined [8]: diameter of the contact neck $d$, diameter of the contact chord $D$, and distance between the centers of the particles $l$. The precision of the measurements was 5%. The measurement error was caused by the glow of the heated particles, which had the effect of washing out their boundaries.

It was established that the formation of interparticle contacts occurs in the following stages: melting of the particle surfaces; migration of the molten layers to the area of contact, where they combine to form a liquid cuff joining the particles; solidification of the alloy upon cooling, completing the formation of a crystalline interparticle neck whose geometry corresponds to the geometry of the cuff. Usually the processes of melting and migration occur simultaneously, and are accompanied by mutual approach of the particles. The nature of the process depends strongly on the radiant energy flux density $P$. If $P$ is relatively small, but large enough to induce surface melting, then approach of the particles occurs only to a certain point, after which the "dumbbell" maintains its shape practically unchanged under further laser irradiation (Fig. 1b). This is explained by