Shrinkage is the only external manifestation of the complex processes occurring during the sintering of various powder metallurgical materials. For this reason, in precision theoretical and experimental studies of these processes, it is necessary to employ reliable, universal shrinkage measuring instruments. However, of the large variety of devices that have been described in the literature [1-9], not one can be regarded as universal for investigations into the kinetics of sintering processes in the laboratory or for the stabilization of the dimensions and quality of sintered parts under industrial conditions. The reason for this is that the field of application of these devices is severely limited by specific (temperature, atmosphere, or design) conditions of experiments for which such instruments are usually specially constructed together with laboratory furnaces and also that various designs may suffer from a number of drawbacks. The lack of devices for the automatic recording of shrinkage curves and the need for the calibration of the majority of instruments, involving the determination of the relative expansion of their measuring system during heating and of the coefficients of linear expansion of test specimens, are the most serious disadvantages, causing considerable difficulties in obtaining and processing experimental data. In this connection, it may be said that a universal apparatus for the measurement of shrinkage during sintering should meet the following requirements:

1. It must be suitable for use in furnaces of all types (laboratory, industrial, vacuum), in various gaseous atmospheres, with various heat supply systems, etc.

2. It must enable shrinkage to be automatically and continually measured and recorded within the range from 0 to 50 mm with an accuracy of ±2-3%.

3. It must be capable of operation within a wide temperature range, up to 3000°C.

In the present article, descriptions are given of the designs of two devices for sintering shrinkage measurement which satisfy these requirements and of experience with their use in an investigation into the sintering kinetics of materials based on refractory metals. Diagrams illustrating the operation of these two gauges, denoted by ID-1 and ID-2, are presented in Fig. 1, while Fig. 2 shows photographs of the actual gauges, constructed for furnaces of various types. The operation of the devices is based on the dilatometric principle, with mechanical [10] and electrical [11] compensation for thermal expansion. Differential inductive coils are used as elements measuring changes in shrinkage during sintering and converting them into electrical signals.

The ID-1 gauge consists of the supporting rod 1, which is placed on the part being sintered 2; the rod 3, with the Armco iron core 4, resting on the supporting rod; the differential inductive coil 5 resting on the moving flange 6; the studs 7, which are rigidly held in the stationary flange 8 and act as guides for the moving flange; the bellows 9, which hermetically connects the moving to the stationary flange; the sealing cap 10, within which the rod with the cores is free to move; the springs 11, which press the moving flange 6 against the support plate 12 with the part via the tube 13 with the disk 14 and the supporting columns 15.

Continuous mechanical compensation for thermal expansion in the ID-1 gauge is made possible by the fact that an upward displacement of the core under the action of thermal expansion is accompanied by an equal and simultaneous displacement of the inductive coil, which rests on the moving flange. As a result, during the heating of the part up to the beginning of sintering, the core remains in the central position.
Fig. 1. Diagrammatic arrangements of devices for shrinkage measurement: a) ID-1 gauge with mechanical compensation for thermal expansion; b) ID-2 gauge with electrical compensation for thermal expansion. For description of parts 1–15 see text.

Fig. 2. Shrinkage gauges constructed for various furnaces: a) single-coil ID-1 gauge (mounted on TsÉP-301 furnace, with protecting cover removed); b) twin-coil ID-2 gauge (mounted on OKB-869 furnace). For description of parts 1–6 see text.