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Method of Measuring Volume Movements of Impression, Model and Prosthetic Base Materials in a Photogrammetric Way.

By

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Introduction.

Volume movements of impression, model and prosthetic base materials decide to a great extent how prosthetic constructions are able to fill the demands required. In laboratory research the interest has mainly been in volume movements in two dimensions only. In this way we talk about linear shrinkage or expansion.

In 1943 DOLDER stated, however, a way to measure movements of a prosthetic base also in three dimensions. KROGH-POULSEN, PAFFENBARGER & SCHOONOVER (1948) worked in a similar way in one of their methods for graphing the contour of the "mucosal" surface of plaster models. The measuring instrument was in both cases a measuring microscope supplied with a nonius. Yet the methods have obvious errors as regards the exact location of the object in the measuring instrument. Error of the measurement is not stated.

In 1946 STRENGER & THAM introduced photogrammetry for measurements of jaws and teeth. The problem was then to get the careful measurement of the forms of the jaws. The result was a complete map of the two jaws. The mean error of measurement was $\pm$ 0.1 mm.

Part of the research work has been done at the Institution of Photogrammetry, Royal Institute of Technology, Stockholm.

Our task has been to work out a method to measure the complicated volume movements, which impression, model and prosthetic base materials undergo during their setting or curing. If possible the volume movements of the prosthesis should be examined even after having been worn by the patient for sometime. The discussion about this subject for the last years makes a method eminently real, which is suitable as well by laboratory as by clinical researches.

Technical Points of View.

The technical methods of measuring, which have hitherto been proposed in dentistry, have not really been a measurement of the object but more a reproduction. Whatever rendering of the forms of the jaws or the teeth is made, there is always a question how the measurement can join exactly enough to certain points given on the surface of the object and which points are marked in a suitable way. If an exact connection could be made to these points at each measurement, the values should always be referred to the chosen co-ordinate system. If the arrangement, however, just permits a fitting of the object by eye or by any simple means, the method must be considered as not exact enough. As a rule the difficulties are not reached in such a case, where the values of measured points or profiles are transferred to a certain coordinate system in the space.

More and more, however, is realized that the reproduction must be made by technical methods of measuring. Some examples of worked-out methods can be mentioned. In the literature there are tests with an acute indicator, an instrument consisting of a measuring scale provided with a metal cusp. The cusp is led down to the object and inaugurated to the points or along the profiles of its surfaces, which will be reproduced. The reading off is then done on the scales of the indicator. The surface indicators, so called, are made according to the same principle. The movements of the indicator can yet be automatically registered. At last a method as per KROGH-POULSEN, PAFFENBARGER & SCHOONOVER can be mentioned, where the jaw model is cut in lamellated plates so that the profile sections were visible, which are wanted to be pictured. All these methods, however, have the same defects as to the exact connection of the measuring values, which are received on the different occasions on which measurements were taken as mentioned above.

A rendering of the form of an object by photogrammetric measuring is on the other hand free of such defects. An accession to the given points can then be made without difficulties as the orientation of the pictures, which are taken of the object at each measurement in the instrument, can be made with the same accuracy in the chosen co-ordinate system. According to the sort of task the measurement can then be done as a decision of the position of single points or a measurement of profiles or a construction of contour lines.

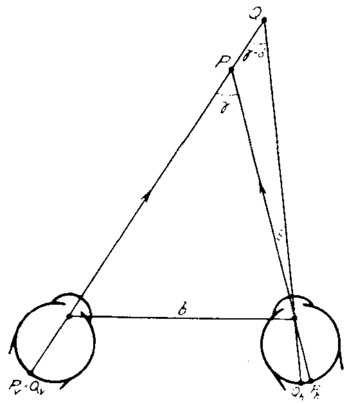


Fig. 1. Geometrical conditions of stereoscopic vision. The axis of the eyes intersect the point P in the convergence angle γ and the point Q in the angle $\gamma - \delta$. Thus, the change of convergence angle is δ.

The Principles of Stereoscopic Vision.

The photogrammetric method is founded on the stereoscopic vision, that is analogously to normal human vision, which is an image of the object pictured on the retina of each eye. To normal eyes these two pictures run together to a plastic picture of the object.

What happens from the geometric point of view at the stereoscopic vision can be seen in Fig. 1. The point is projected on P_h and P_v on the respective retinas of the eyes. To be able to regard the point P on the whole, it is necessary that the eye directions are adjusted towards the point in question, *i. e.* that the convergence adjustment is the right one. At the same time the eyes must be accommodated to the distance of the point. This accommodation is, however, released automatically by the convergence adjustment.

Regarding another point Q an alteration of the convergent angle is required with the sequent adjustment of the accommodation. By that the point Q is apprehended at another distance than P. For such a judgement of the distance is, however, that the alteration of the convergent angle is not below the minimum value of the sensibility of the eye. Nor the convergent angle itself is allowed to go below the boundary, out of which on the whole the sensitiveness of the eye is not enough for deciding the mutual depths of different objects.

Now we suppose that the object — instead of being regarded by the normal vision — is photographed in such a way that the optical axis coincides with the respective eye directions. If then the pictures received are placed at the same mutual places in front of the eyes, the object must visibly appear plastically in the corresponding way as at the normal vision. This is what principally happens by photogrammetric methods. That is the reason why the photographing must always be done so that qualifications are created for a stereoscopic vision of the object, that is that the object is photographed from two sides in a way, which is technically correct. On regarding the received pair of stereoscopic pictures, so called, with or without optical means, we will see an "optical model", as we say, of the object. If at the same time the pictures are mutually placed in the exact way as on taking the photos, the really photogrammetric measurement can begin.

The Principles of Photogrammetric Measuring.

To make clear how the measurement is done an example is chosen from mapping from the air of a given area, which is schematically shown at Fig. 2. The two pictures, which are visible at the figure, belong to an arial strip survey and are taken by a vertical camera axis and they cover each other in the direction of flight over the ground to a certain degree. On mapping a continuous area the overlap is about 60 per cent. If the pictures are so photographed that the whole object is visible at the pair of pictures, there are qualifications for reconstructing the object out of it. The reconstruction is principally executed so that the taken negatives or the diapositives rephotographed are placed in a stereo-instrument. This instrument is provided with projectors of the same appearance as a camera, that is with a lens and a negative holder. Each holder is further provided with a lighting arrangement. The illuminated picture, which is projected through the objective, can be regarded subjectively by a lens or objectively by a projection on a substratum. If the two negatives are illuminated after being brought into the right reciprocal orientation,

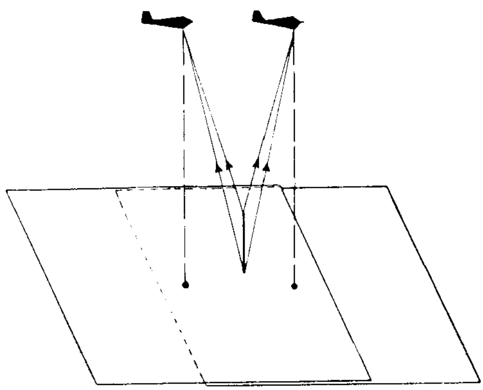


Fig. 2. Schematical illustration of a pair of stereoscopic pictures belonging to an aerial strip survey. About 60 % of the pictures overlap.

there will be received a complete reconstruction of the object. Instead of photographing light rays from the ground have given rise to a picture on the negative, at stereoscopic vision the rays will go in the opposite direction. The rays, belonging to the two objects, then intersect, as seen at fig. 3. By that the scale of the model is determined by help of certain known points on the object, control points, so called. After having an optical model, drawn to scale in this way, we can inversely chose points, which are adjusted in the instrument. On scales belonging to the instrument we can read off the three co-ordinate values of each point in the chosen co-ordinate system. By adjustments one after another the mutual places in space of arbitrary points can thus be decided, even profile lines be measured or contour lines be constructed.

Compared with the surface indicating methods mentioned above the advantages of the photogrammetric methods are thus that all measured points can be transferred to a given co-ordinate system.

Further, control points chosen can directly join the same co-ordinate system. Besides, there is the advantage that we are not limited to certain points of the object but can arbitrarily chose the points. Finally, a measurement can be repeated at any time as the stereoscopic model at each measurement is transferred to its given coordinate system. It is also of importance that supplemental measurements can be executed at any time.

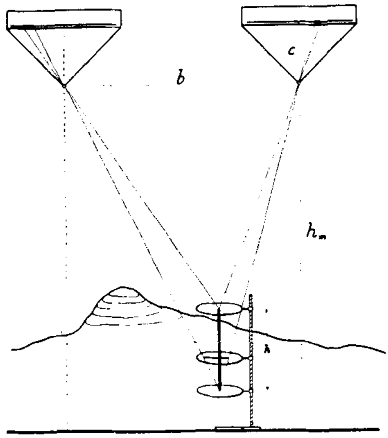


Fig. 3. Schematical illustration of a stereo-measurement in Multiplex. In the ground a "flaggstaff" is marked out. Its height will be measured from top to and foot by means of the "measuring mark" in the centre of the instrument table. The numerical value of the height can be directly read off on the scale.

Testing Arrangements.

a. Odontological Arrangements. To make clear the application of the photogrammetric method we have chosen an upper jaw model without teeth, with ridges in good conditions without undercuts and with the palate evenly arched. In order to get rid of the volume movements influencing the measurements, the master-model was made of metal. Control points, which are necessary for the photogrammetric measuring were stamped into the vestibulum of the model. The mouldings, however, were beset with difficulties, mainly due to the stamped marks, which stood out like elevations of the negatives of acrylics or vulcanite. It means that in one case the adjustment of the measuring mark of the stereoinstrument on a control point must be done to the lower surface of the stamped marks, in the other case to the upper one, which appeared like an elevation, as mentioned above. In principle it does not mean anything, but in practice systematic errors can arise. After repeated tests triangular-formed marks were chosen, which were stamped into the master-model. The side of the triangle was 1 mm and the depths of the stampmark 0.5 mm (Fig. 7).

As a further applicable object test specimens were then chosen of vulcanite and acrylic. At first plaster models were made by

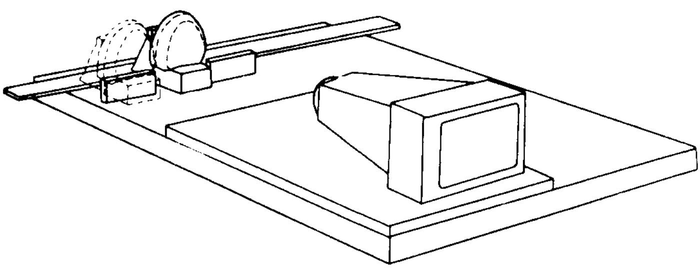
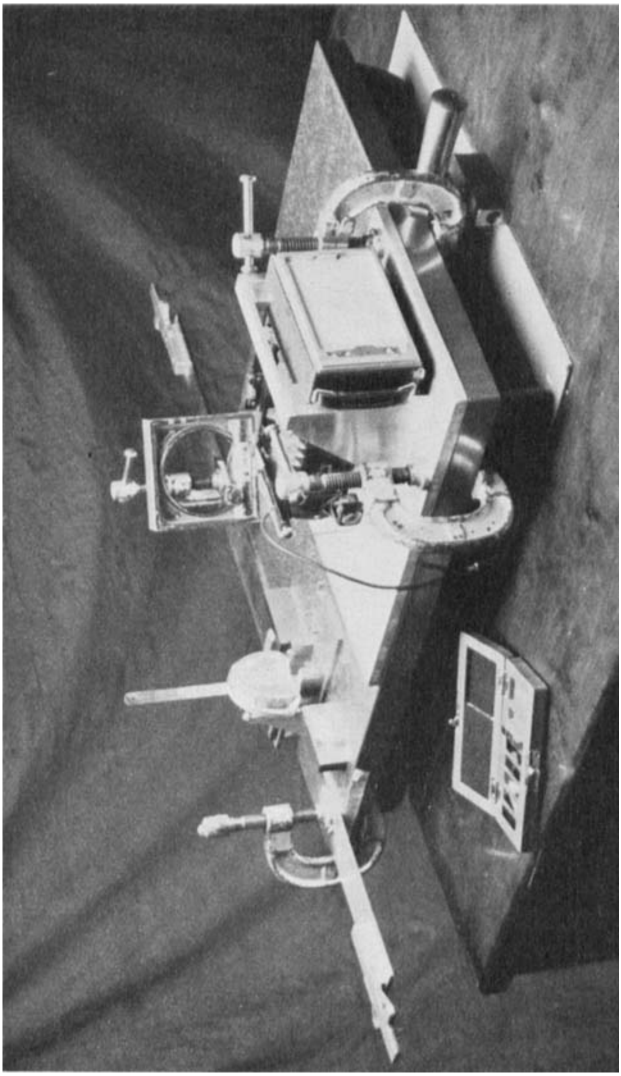


Fig. 4. Schematical illustration of the photographing of the master model and the test specimens. The camera is fixed and the object is moved.

duplicating with alginate on standard stipulations and the same kind of stone. Over the whole duplicated model was placed a layer of wax of one sheet's thickness and over the alveolar ridges three more layers of the same thickness and about 10 mm broad. By fissures in the vestibular part of the model we made sure that the test specimens got the same base surface. Their rims were made parallel with the basic plan of the plaster model. In this way we got specimens, which as a matter of fact all had about the same volume. On producing the test specimens of acrylics the mucous surface was tinfoiled and the tongue surface glazed. No isolation was used for vulcanite. All specimens were cured in identical conditions. They were not polished.

b. Photogrammetric Arrangements. From the photogrammetric point of view the photographing itself was the greatest problem, depending on the fact that there are no cameras for photogrammetric purposes which are suitable for close-up photographing. The stereocameras, which are introduced on the market, do not admit larger scales than about 1 : 10 between an object and its picture. A suitable camera must be procured in our case. As the application of the method just intended a comparison between the master-model and the test specimen the problem was limited to



5. Photographic arrangements.

the *relative* changes between them. That is the reason why it is not necessary making the same claim to the camera, which normally must be done in photogrammetry. A good fitting amateur camera could be used in this case. From the photogrammetric point of view such a camera differs from a measuring camera by the fact that its inner orientation is not known.

Instead of moving the camera itself in front of the object (Fig. 2) we have of practical reasons arranged it so that the object is moved. In both cases the geometric conditions will be the same. The camera is clasped to its place in a way that together with its support it can be considered as a stiff system. By an arrangement in front of the camera the object can be moved in parallel directions to itself and its position can be read off from a scale provided with a nonius.

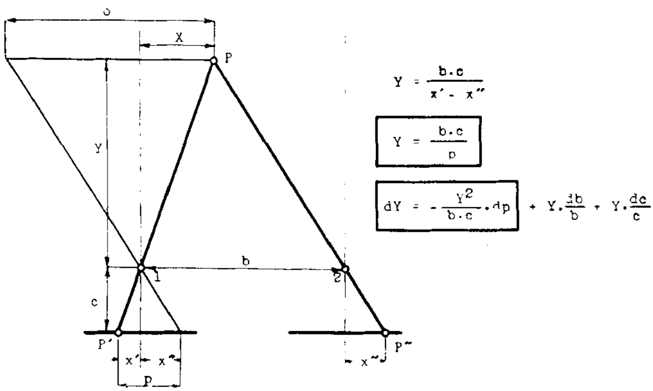


Fig. 6. The "normal case" of photogrammetry.

In accordance with this principle the photographing is executed as per Fig. 4 and 5. On the schematical figure first mentioned the two positions of the master-model are drawn in an illustrating view. For that purpose a camera was chosen of the brand of Zeiss-Ikon, 1: 3.5 and a focal distance of 10.5 cm. With a basis of 4 cm, through which the whole breadth of the photo plate of the pictures, 6.5 × 9 cm, could be used, we got a total distance of about 450 mm between the object and the negative plane, corresponding to a scale of 1: 1.4. The whole testing arrangement could by this be placed on a "flat plate" so called, by which a high precision could be guaranteed for the moving of the object parallel to itself. As seen in Fig. 5 the camera is clasped in a metal frame. The object was placed at a nonius arrangement, belonging to the ruler of a coordinatograph. The length of the basis could by this be decided with an exactness of the adjustment of 0.1 mm. By the perpendicular adjustment of the ruler to the optical axis of the camera the photogrammetric "normal case" was received (Fig. 6).

The loss of collimating marks on the camera was a problem. The

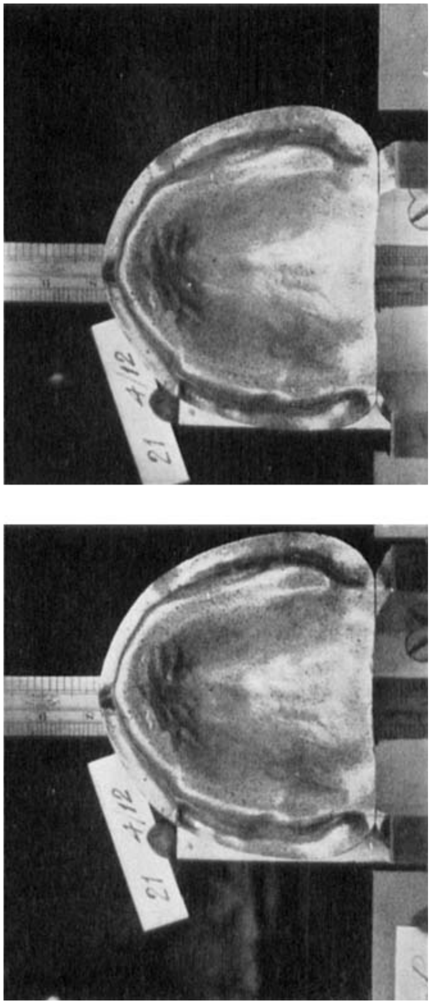


Fig. 7. The pair of pictures of the master model.

problem was solved by help of "fitting pieces" of C. E. Johansson-type (Fig. 5), which were placed on and on both sides of the object in order to be visible on the picture. As the support was a flat-plate and the camera was clasped in its position, the photographed horizontal upper edges of the "fitting pieces" could serve as collimating marks at the reciprocal orientation of the pictures at the stereomeasuring.

In order to get the photogrammetric normal case, the ruler must be adjusted perpendicularly to the optical axis of the camera.

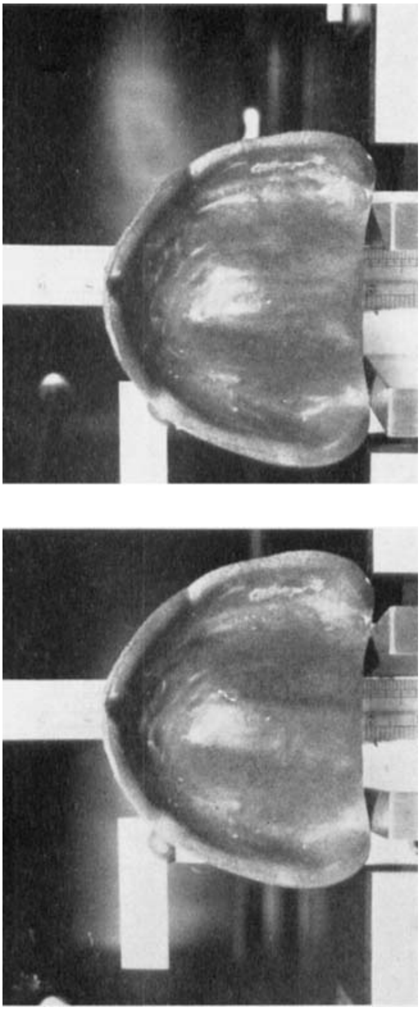


Fig. 8. The pair of pictures of the test specimen of acrylic.

As a direct decision of the latter should be detailed, it was received by measuring of angles by a theodolite to upper and lower edges of the object in its two positions upon the ground glass plate of the camera. The position of the ruler was then adjusted so that the angle measured agreed with these.

The photographing was performed by help of granulated microplates.

Illustrations of a pair of stereoscopic pictures of a master-model and a test specimen are to be seen, Figs. 7—9.

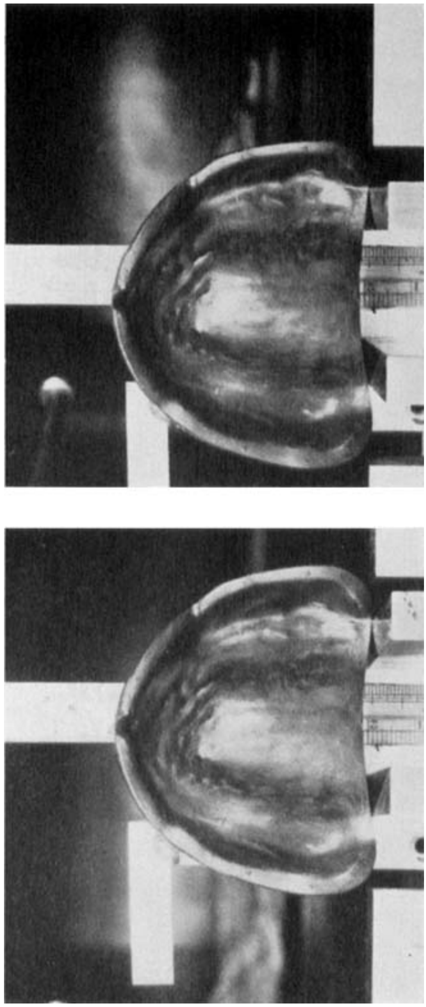


Fig. 9. The pair of pictures of the test specimen of vulcanite.

The Performance of the Measuring.

For the measuring a coordinate system (xy) was chosen in such a way that the origo of the system was placed at the lower control point in the left vestibulum of the model and with the positive direction of the x-axis to the right (Fig. 10). Perpendicularly to the x-axis the y-axis is chosen and is positive in the ventral direction, which is seen in the figure. Origo at the chosen point was marked with 10 and the corresponding control point in the right vestibulum of the model with 20. The line 10—20 was chosen to a reference line at a division of the model in profiles, partly parallel, partly perpendicular to it. For that purpose the distance 10—20 was divided in 10 parts, 10, 11, 12, . . . 20, which were not marked off on the specimen but were directly reckoned from the measuring values of the terminal points 10 and 20. Through the medium point 15 a profile was further chosen perpendicularly to the line

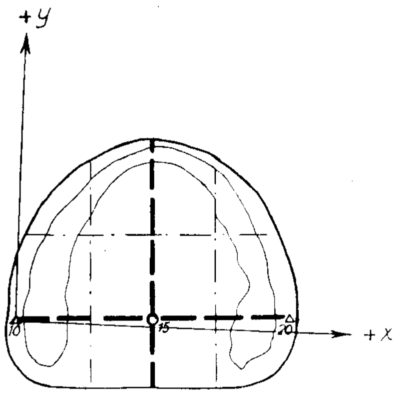


Fig. 10. The choice of co-ordinate system and measuring sections on the model.

10—20, which in an identical way was divided in parts of the same size. To avoid double-marking the points along this line were called 148, 149, 150 . . . As only a determination of the method was in principle intended, the measuring was limited to a profile along the line 10—20 and another profile perpendicularly to the former through its medium point 15 (150). If the measurings should be increased to several profiles through the mentioned points, the model should be overdrawn by a square system.

The stereomeasuring was executed in a stereocomparator as in Fig. 11. This instrument is built on the idea that the pair of stereoscopic pictures belong to the normal case. As the two negatives have been on the same plane on the photographing, they are then placed in the instrument in a similar way into holders, intended for this purpose. The measurement is a measuring of parallaxes that is a measuring point after point of the quantity p in the formula stated in Fig. 6. The three coordinates of the measuring points, x, y and z, can be reckoned from the known constants the base b and the camera-constant (the focal distance) c.

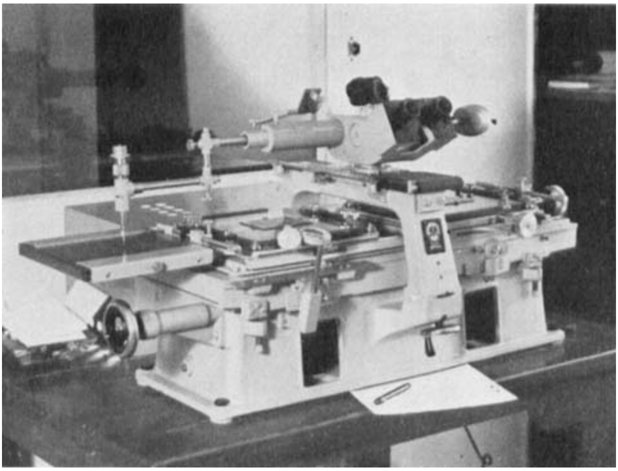


Fig. 11. Zeiss stereocomparator.

Measuring Results.

a. Method. The performance of the method in detail was executed by the help of the master-model. By deciding in the stereocomparator at first the components of x and y of the line 10—12 in the coordinate system, the adjustment values of all the partial points could be reckoned. The camera constant c was empirically determined by the help of the graduated scale, which was placed on the holder of the test specimen immediately behind the latter (Fig. 5). The distance *a* from the negative plane to the scale was measured. By transformation of the formula of the normal case for x and y we arrive at

$$c = a \cdot \frac{x^1}{x + x^1}$$

and by this the product b · c is known. By the latter can then the three space coordinates be reckoned from the measuring values of the parallaxis of the different partial points. The received z-values have further been transformed in such a way that they state the depths of the different partial points in relation to the line 10—20 as a zero-line. The same thing was done in a corresponding way along the profile through the point 150.

To decide *the error of the method* the master-model has been

Table 1.

Z-values and Their Differences for the Master-model of the Pairs of Stereoscopic Pictures 1 a and 1 b.

Frontal Sections

Point	1 a	1 b	1 a—1 b	Reduced Values 1 a—1 b
10.2	0	0	0	— 0.06
11	+ 10.543	+ 10.466	+ 0.08	+ 0.01
12	+ 9.599	+ 9.450	+ 0.15	+ 0.08
13	+ 3.182	+ 3.135	+ 0.05	— 0.02
14	— 1.614	— 1.674	+ 0.06	— 0.01
15	— 3.778	— 3.806	+ 0.03	— 0.04
16	— 1.570	— 1.650	+ 0.08	+ 0.01
17	+ 2.415	+ 2.303	+ 0.11	+ 0.04
18	+ 8.582	+ 8.503	+ 0.08	+ 0.01
19	+ 11.254	+ 11.138	+ 0.12	+ 0.04
19.8	0	0	0	— 0.07

Table 2.

Z-values and Their Differences for the Master-model of the Pairs of Stereoscopic Pictures 1 a, 1 b and 2.

Frontal Sections

Point	Reduced Values $\frac{1a+1b}{2}$	2	$\frac{1a+1b}{2}-2$	Reduced Values $\frac{1a+1b}{2}-2$
10.2	+ 0.032	0	+ 0.03	— 0.05
11	+ 10.537	+ 10.647	— 0.11	— 0.19
12	+ 9.557	+ 9.358	+ 0.20	+ 0.14
13	+ 3.192	+ 2.965	+ 0.23	+ 0.18
14	— 1.611	— 1.608	0	— 0.04
15	— 3.758	— 3.872	+ 0.11	+ 0.09
16	— 1.576	— 1.687	+ 0.11	+ 0.10
17	+ 2.394	+ 2.531	— 0.14	— 0.14
18	+ 8.578	+ 8.750	— 0.17	— 0.16
19	+ 11.232	+ 11.242	— 0.01	+ 0.01
19.8	+ 0.036	0	+ 0.04	+ 0.07

Sagittal Sections

Point	1 a	2	1 a — 2
149	+ 1.787	+ 1.751	+ 0.04
150	0	0	0
151	— 1.263	— 1.154	— 0.11
152	— 1.630	— 1.565	— 0.06
153	0	0	0
154	+ 4.872	+ 4.848	+ 0.02
155	+ 10.735	+ 10.778	— 0.04

photographed several times. The measurements were then done partly in one pair of pictures on different measuring occasions, partly in different pairs of pictures photographed on similar conditions. On the first measurement that error of method can visibly be decided, which arises from accidental errors at the measuring itself, whereas the last mentioned measurement shall be influenced

Table 3.

Z-values of Test Specimens of Acrylic and Vulcanite.

Point	Acrylic	Vulcanite
	Frontal Sections	
10.2	0	0
11	+ 10.668	+ 10.774
12	+ 9.481	+ 9.971
13	+ 1.971	+ 2.162
14	— 2.398	— 2.293
15	— 4.491	— 4.497
16	— 1.965	— 2.150
17	+ 3.666	+ 3.102
18	+ 10.274	+ 9.949
19	+ 8.794	+ 9.403
19.8	0	0
	Sagittal Sections	
149	+ 1.787	+ 1.708
150	0	0
151	— 1.224	— 1.280
152	— 1.451	— 1.453
153	0	0
154	+ 4.904	+ 4.631
155	+ 10.951	+ 11.029

by accidental errors not only by the measuring but also by the photographing.

From all tests partly a pair of picture 1 was chosen, which was measured twice, partly another pair of picture 2. The reckoned and reduced z-values will be seen from the following comprehensive survey.

Although the measurements must be limited to twice respectively two pairs of pictures we have tried to state an error of the method. Statistically, however, the material is too slight. The profile values of the two tests have been moved in parallel and turned in relation to each other so that they attach as close as possible. The remaining maximum error is by that of the pair of pictures 1 a and 1 b 0.08 mm (see table 1). The comparison

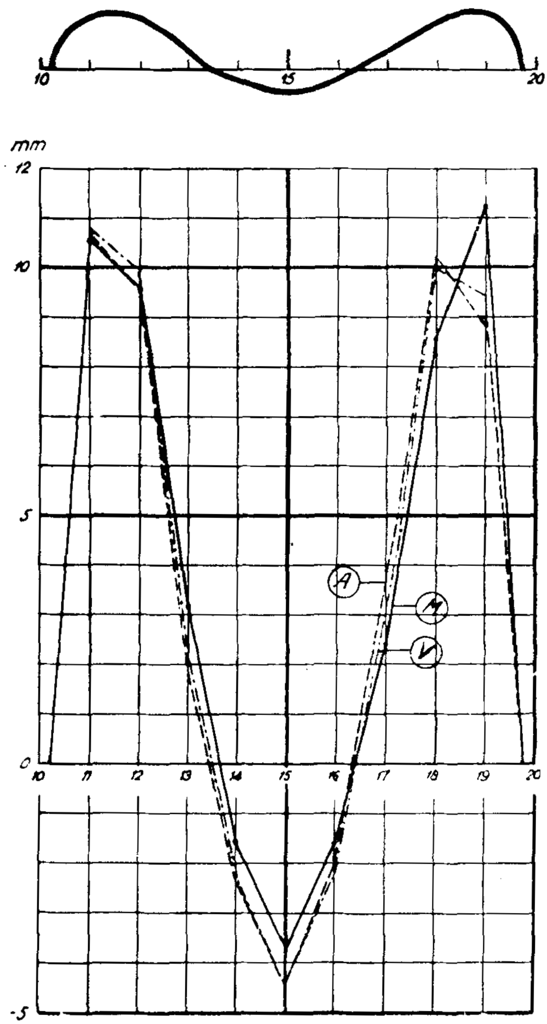


Fig. 12. Result of the measurement of the frontal section. The figure above shows the section in normal proportions. The diagram below is drawn with a height scale × 10. M = metal master model, A = acrylic and V = vulcanite specimen.

between the pairs of pictures 1 and 2 gave in a corresponding way a maximum error of 0.19 mm (see table 2). Comparatively it can be mentioned that we can expect the mean error not to be more than 0.06 mm with exact testing arrangements.

b. Applications. The employment of the method for practical use was examined twice on two test specimens of acrylic and

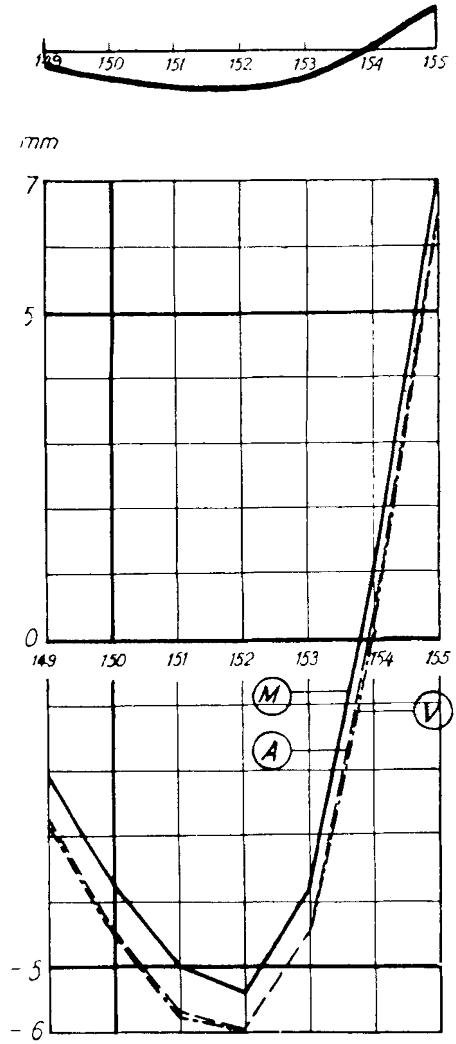


Fig. 13. Corresponding result in the sagittal section, see fig. 12.

vulcanite. The measurements were made by the same metod as for the master-model. In a similar way the profile 10—20 was compared to the other profile perpendicularly cut through the point 150 of the master-model and the test specimen. The reckoned z-values of the acrylic and vulcanite test specimens are seen from table 3.

The values of the table are graphically given an account of in

Fig. 12. The diagrams show that the maximum of the deviations is about 2 mm. The deviations are especially visible in the frontal section 10—20, while those of the sagittal section through point 150 are insignificant.

Finally we must emphasize that the aim has just been to state a method, which measuring-technically is more reliable than those, which hitherto used. For scientific purpose the testing arrangements must and should be improved in detail. As a result of this fact the measuring values of the examined prosthetic base materials, of course, can not be considered as typical for the quality of these materials.

Conclusions.

1. The photogrammetric testing arrangement has principally functioned satisfactorily.

2. The results of the technical measurements are acceptable with an error of about 0.1 mm.

3. The method is suitable among other things for examination of the exactness of impression materials, volume movements of model materials and the ability of prosthetic base materials for surface adaption.

4. The greatest value of the method is, however, that eventual changes of forms of different prostheses or just one prosthesis can be followed during an arbitrary time.

Zusammenfassung.

Die Verfasser haben eine photogrammetrische Methode der Messung der Volumenbewegungen der Abdruck-, Modell- und Prothesebasismaterialien ausgearbeitet und stellen fest:

1. Die photogrammetrische Versuchsanordnung hat prinzipiell befriedigend funktioniert und dürfte als Typ dienen können. Für den wissenschaftlichen Bedarf lässt sie sich jedoch, was die Einzelheiten betrifft, verbessern.

2. In messungstechnischer Hinsicht können die Ergebnisse als anerkannt gelten mit einem Fehler der Methode von ungefähr 0.1 mm.

3. Die Methode ist u. a. günstig für das Probieren der Genauigkeit der Abdruckmaterialien, der Volumenbewegungen der Modellmaterialien und der Fähigkeit der Prothesebasismaterialien zu genauer Flächenanpassung.

4. Die grösste Bedeutung der Methode besteht jedoch darin, dass verschiedene Prothesen oder dieselbe Prothese betreffs eventuell eintretender Formveränderungen in beliebiger Zeit bei klinisch-experimentellen Proben beobachtet werden können.

Résumé.

Les auteurs décrivent une méthode de mesurer les mouvements du volume des matériaux d'empreinte, de modèle et de base prothétique dans la manière photogrammétrique et ils constatent:

1. Principalement l'arrangement photogrammétrique d'expérience a fonctionné satisfaisant et peut servir de type.
2. Du point de vue de mesurage technique les resultats sont acceptables avec une faute de méthode d'environ 0.1 mm.
3. Entre autres la méthode est applicable à une analyse de la précision des matériaux d'empreinte, des mouvements du volume des matériaux de modèle et de la capacité des matériaux de base prothétique à l'adaption contre la surface.
4. La plus grande importance de la méthode réside pourtant en ceci que les prothèses différentes, ou une prothèse seulement, peuvent être suivies en question des changements de la forme eventuellement parus pendant un temps arbitraire aux analyses cliniques-expérimentales.

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