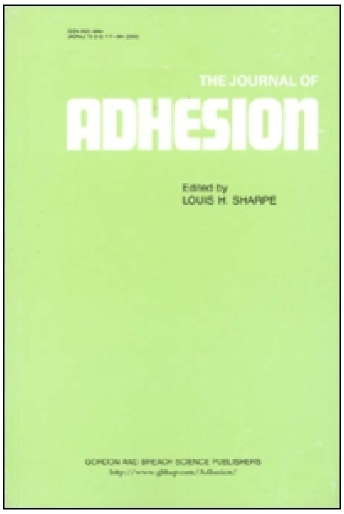

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Accurate High-speed Assembly of Optical Components in Optical Scanning Systems using UV-curing Adhesives: A Positional and Stability Study†

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In the miniaturized designs of optical scanning systems, UV-curing adhesives have been substituted for screws and bolts. The assembly of delicate optical components enforces stringent requirements on positional accuracy and stability after temperature and humidity cycle testing. The influence of the UV-curing adhesive is mainly determined by its polymerization shrinkage (typically more than 6%). With low amounts of Aerosil® fillers (5% by weight), shrinkage values of 3% can be attained. Optimized adhesive constructions lead to close positional tolerances (0.5 μm) and angular displacements (0.1 mrad).

KEY WORDS UV-curing adhesives; photopolymerized adhesives; optical scanning systems; miniaturization; positional accuracy and stability; high-speed assembly.

INTRODUCTION

The earliest designs of optical scanning systems, e.g., for the Compact Disc digital audio disc and LaserVision video disc players, have a majority of old-fashioned fastening methods: screws, bolts

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and other mechanical means such as snap connections for fixing optical components (lenses, mirrors, gratings, laser and detector). Most of the screws and bolts also have an adjusting function, which means that assembly and adjustment of the optical system is a rather time-consuming and consequently expensive method. In principle, this prevents mass-production. Also, these old-fashioned but familiar methods were used because of the lack of large quantities of small, solid-state lasers. This prevented miniaturization of the laser light-path unit. Even so, the most important reason was suspicion of the use of adhesives in these delicate constructions, caused by bad experiences in the past and unfamiliarity with the present state of the adhesives art. Rapid developments in the adhesives field in recent years, expecially those of UV-curing adhesives, have opened up many new possibilities, and their use in all kinds of electronics applications (*e.g.* wire tacking, surface mounting of lead-less components) has increased rapidly.

In the electronics industry the field of photopolymerization has been studied intensively, and the technique has proved to be versatile for a number of coating applications[1-6] and fixing applications.[6,7]. With the recent availability of solid-state, semiconductor lasers, themselves small optical units, and UV-curing adhesives, miniaturization and mass production of laser light-path units looks promising and within profitable reach.

Therefore, recent optical designs for the consumer market, as in the case of the Compact Disc player, feature more and more adhesive joints; joints that are mainly made with UV-curing, epoxy and cyanoacrylate adhesives. Using these adhesives, most of the positional and dimensional stabilities are introduced during assembly of the optical components.

The key components in the optical path of the Compact Disc player are the laser, the beam-splitter, the collimator and objective lens, and the detector. These components, and their functions, are shown schematically in Figure 1. These and similar Compact Disc designs are now manufactured in large quantities for consumer applications.

In this paper we focus on the LaserVision player, which is partly comparable with the Compact Disc player but requires some additional optical components because digital video information also has to be processed. This adds supplementary requirements on

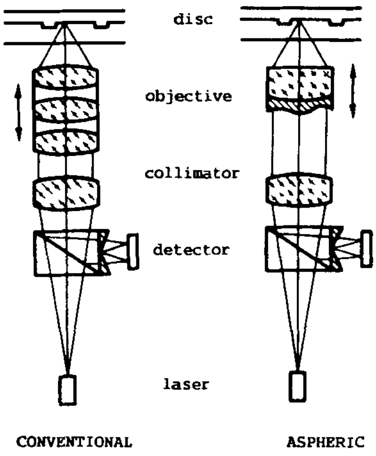


FIGURE 1 Key components in a Compact Disc optical scanning system.

positional and dimensional stability and makes the laser light-path unit more difficult to manufacture. We shall describe the influence of different adhesives on mechanical and processing parameters, and the development of the adhesive constructs that make it possible to meet the stability requirements of this optical scanning system, which finds its main use in professional applications.

DESIGN

The differences between the LaserVision and Compact Disc player, with regard to the light-path, are caused by some typical system parameters. The Compact Disc player is an audio apparatus, and has to produce only one signal; the audio signal. The LaserVision player has to produce two signals; an audio and a video signal. The video signal is the more sensitive, and therefore requires a better tracking accuracy. The Compact Disc player needs only one scanning laser spot to read and track the audio signal, whereas the LaserVision player has one scanning laser spot with a read-out function, and two auxiliary spots that have a radial control function.

A typical LaserVision requirement is also the ability of the

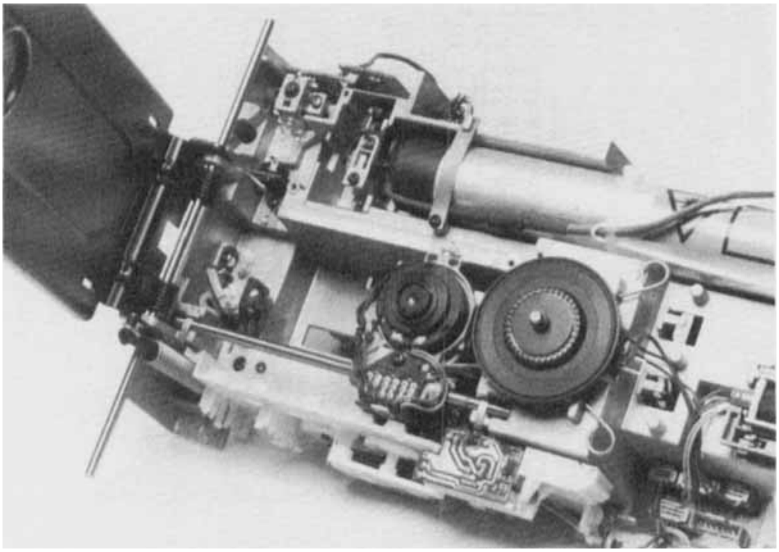


FIGURE 2 Design of an old-fashioned LaserVision video optical scanning system.

scanning laser spot to jump, within 17 ms, over television lines in the blank area which contain no information.

These differences, plus several others, require supplementary optical components, such as a grating and a tangential tracking mirror. Figure 2 is a photograph of the LaserVision player, showing an old-fashioned laser light-path. The different optical components and the large amount of space for the screws and bolts, and the Helium/Neon laser located at the top right-hand, are clearly recognizable. The laser light-path shown in this photograph comprises nine optical components from laser to detector. This light-path was completely redesigned, and a new miniaturized unit was developed, based on all-UV-curing adhesive constructions with the same nine components.

Adhesive Requirements

The starting points for our investigations into adhesive fixing were the requirements set by the laser light-path designer and, obviously, those that arise from the desire to develop a mass-production process. Given in random order, the following requirements had to be met:

1. The adhesive joint must be strong over the whole operating temperature range. In practice, between 5 and 55°C would be sufficient. For safety, transport and extreme circumstances, a range of −40 to +70°C with relative humidity up to 95%, were demanded.
2. The processing, application and curing of the adhesive has to be simple, easy and quick.
3. The adhesive and/or the construction must meet both the positional and stability tolerances. The dimensional stability must be high after cyclic temperature and humidity tests.
4. The adhesive construction has to allow, and preferably promote, the miniaturization of the laser light-path.
5. The adhesive and/or the construction should allow the use of different substrate materials (glass, plastics, metal), sometimes worked up as sub-assemblies each with their own physical properties and assembly tolerances. Depending on their optical function, the components may have wide, as well as very close, tolerances.

Selection of the adhesive system is strongly influenced by the first three requirements mentioned above; properly selected UV-curing adhesives with a very long pot life should meet these. In addition, UV-curing adhesives have the advantage, compared with other adhesives, that they start to cure immediately after the joint is exposed to UV radiation. This property allows handling and positioning during optical component mounting.

With respect to positional stability, a disadvantage of UV-curing adhesives is that they can, depending on molecular structure and composition, exhibit polymerization shrinkage up to 20%. This is usually compensated by adding fillers, which adversely influence the adhesive properties. A further disadvantage concerns their temperature behaviour; UV-curing adhesives have a relatively low glass transition temperature (T_g).

In general for UV-curing adhesives, the T_g is determined by the molecular structure and physical constraints that are dependent on: exothermic heat of reaction; heat generated by the UV source; the ambient working temperature. This means that the T_g will be near, or some degrees above, ambient. To obtain dimensionally stable joints at higher temperatures, some additional heating at a higher temperature is necessary.

Construction

The optical components, as in Figure 2, are fixed by screws, etc., in an aluminium housing; this has thick walls and ribs that are necessary, on the one hand, to guarantee stability of the laser light-path unit and, on the other, to enable mounting of the optical

TABLE I
Positional and stability tolerances for some optical components of the solid-state laser light-path

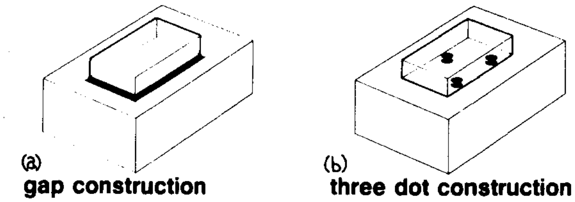
Component	Direction	Positional	Stability
Collimating lens	z	50	200
	α	1	1
	β	1	1
Grating	z	100	200
	α	20	1
	β	20	1
Laser	x	25	0.6
	y	25	0.6
	z	50	0.5
	α	3	3
	β	3	3
Plane parallel plate	x	100	free
	y	100	free
	z	20	0.8
	α	1.5	0.03
	β	1.5	0.03
Detector	x	0.6	0.6
	y	0.6	0.6
	z	0.5	0.5
	α	10	17
	β	10	17

Notes: 1. x, y, z tolerances in μm for direction
2. α, β tolerances in mrad for rotation
3. α, is rotation about x; β is rotation about y

components (*e.g.*, threaded holes). With adhesives, the thick walls can, in principle, be obviated. However, special constructions are then required that should also provide the possibility to position the optical components within the desired tolerances and fulfil the stability demands.

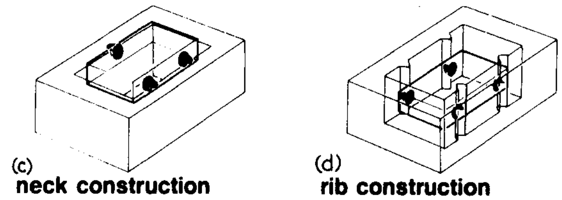
These special constructions depend on the magnitude and direction (x, y, z, α, β) of the various tolerances. For some of the components of the laser light-path, the tolerances and directions are given in Table I. Depending on the function of the component, the tolerances vary from very close to relatively wide.

Optical components, for instance the grating, with rather large positional and rotational tolerances would, in principle, allow a gap construction, as shown in Figure 3a. However, adhesive joints based on these types of construction are likely to cause big internal and external tensions. These cannot be avoided when substrate materials with different physical properties (*e.g.*, Young's modulus, thermal expansion coefficient) have to be used. Also, of course, the physical properties (Young's modulus, thermal expansion coefficient) of the adhesive will contribute to the tension in the construction. In addition, the polymerization shrinkage of the adhesive during curing will lead to positional instability. A way to overcome tension problems is to use construtions as in Figure 3b.



(a) gap construction

(b) three dot construction



(c) neck construction

(d) rib construction

FIGURE 3 Examples of adhesive constructions.

With a gap-construction based on three adhesive dots, tension in the joint can be neglected; the dots act as an elastic bridge. However, stability problems arising from adhesive shrinkage and differences in thermal expansion coefficient will still exist in this case. This is important for joints with closer positional and stability tolerances. For example, the plane parallel plate requires an adhesive construction that prevents movement in delicate directions. Table I shows that, for the plane parallel plate, the x and y positional tolerances are relatively large (100 μm) compared with the z positional tolerance (20 μm).

The stability tolerances differ largely from these values and actually only a very high stability (0.8 μm) in the direction of the optical (z) axis is required. The most delicate tolerances, however, are in rotation (α and β) about the x and y axes. For the plane parallel plate, the positional and stability tolerances are 1.5 mrad and 0.3 mrad respectively. These close tolerances require special adhesive constructions, designed so that the forces, and thus the displacements, due to polymerization shrinkage and differences in thermal expansion coefficients, are prevented in the z-direction. It will be clear that further requirements can be set for the ideal adhesive: *viz.*, zero polymerization shrinkage and a thermal expansion coefficient that matches those of the different substrates.

EXPERIMENTAL

Materials and Pre-treatments

Most of the experiments with model constructions were done using glass and aluminium ($AlSi_8Cu_3$ (226D)) substrates. The substrate surfaces were degreased with acetone or ethanol before use. Loctite 358 (Loctite, Dublin, Ireland) adhesive was used as supplied. Modification of the adhesive with Aerosil R202 and Bentone SD-2 fillers was done by hand mixing, after which the adhesives were degassed to avoid trapping air. Aerosil R202 is a fumed hydrophobic silicon dioxide, specific surface 200 m^2/g and treated with silicon fluid. Bentone SD-2 is a clay mineral (smectite), pre-coated with a quaternary ammonium compound.

Adhesive Properties

The viscosities of the adhesive and its modifications were measured at 23°C on a Rheomat 30 viscosimeter with a cylindrical measuring system, ND 25 for the pure adhesive; ND 14 for the modified material.

The reactivity of the adhesives was measured on a differential scanning calorimeter DSC 1B (Perkin Elmer), specially equipped with a UV light source to monitor photopolymerization reactions. This light source was obtained from Macam Photometrics Ltd, and contains a Philips lamp HPA400, IR filter and liquid light guides with a 20 mm^2 effective area. The light intensity measured at 10 mm distance from the end of the light guide was 50 mW/cm^2.

The adhesive shrinkage during UV-curing was measured on our own specifically constructed equipment.[4] The Young's modulus of the cured adhesive was determined on a dynamic mechanical thermal analyser from Polymer Laboratories, operating at 1 Hz. The thermal expansion coefficient was established with the TMA 40 module of a Mettler TA 3000 thermal analysis system. Typical sample dimensions: thickness 200 μm, diameter 8 mm, measured under a load of 0.1 N. Strengths were determined on a Zwick 1464 tensile tester, using a pull speed of 1.25 mm/min. Normal clamping of glass substrates presented problems, so the jig shown in Figure 4 was used. The samples were tested under shear, with an effective adhesive area of 140 mm^2.

Stability Measurements

Positional and stability accuracy were measured either mechanically or optically, depending on the required degree of accuracy. Not all the optical components were studied for stability. Most of the stability investigations were done on a model system, using mirrors; displacements were recorded mechanically, as shown in Figure 5. This mechanical method is suitable only for the large tolerances; its accuracy is about 1 μm. The close tolerances were measured optically, using the principle shown in Figure 6. This equipment enables measurements in z displacement of $\Delta z = 0.2\ \mu$m, and x and y rotational displacements of $\Delta\alpha$, $\Delta\beta = 0.03$ mrad.

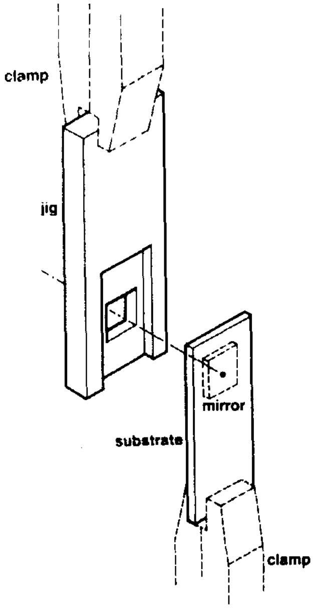


FIGURE 4 Schematic drawing of the shear-strength measurement jig.

Stability tests were carried out in a Grenco GKSD 500.80 climatic chamber, using a cyclic temperature-humidity programme as given in the profiles shown in Figure 7.

RESULTS AND DISCUSSION

Adhesive Properties

As stated in the introduction, shrinkage of the UV-curing adhesive was expected to be the biggest problem in obtaining stable constructions. We investigated adhesives from various suppliers and found that, in general, the shrinkage of the UV-curing adhesives lies between 6 and 12%. For instance, Loctite 358 shrinkage is around 6%. With delicate positional tolerances, unacceptable results can thus be expected. We tried to overcome these excessive shrinkage values by using thixotropic fillers R202 and SD-2.

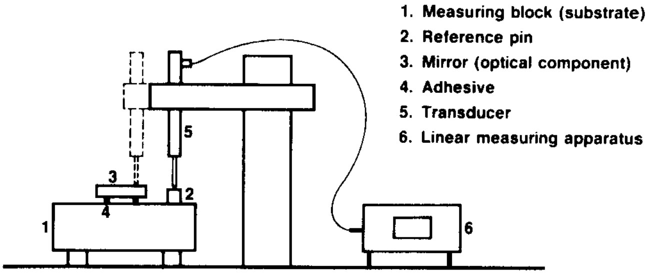


FIGURE 5 Mechanical measuring method principle.

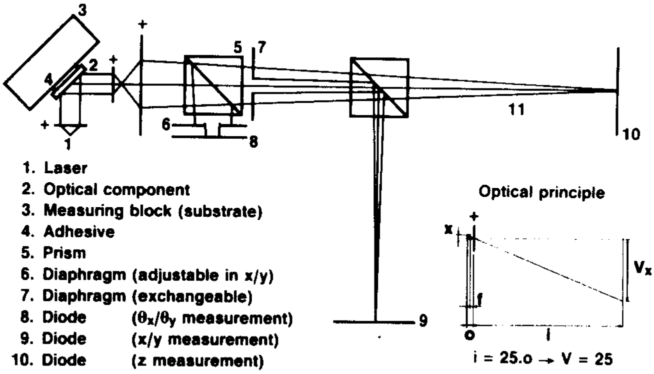


FIGURE 6 Optical measuring method principle.

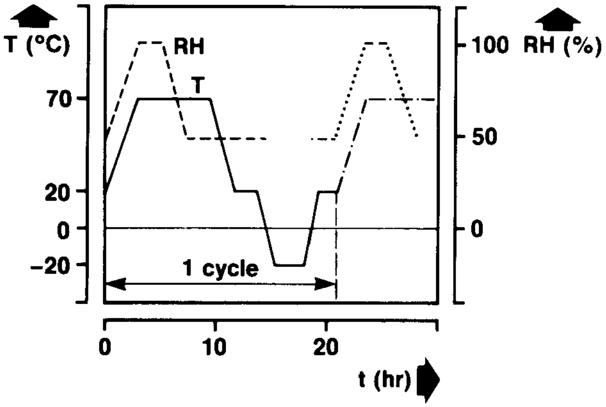


FIGURE 7 Cyclic temperature-humidity test profile.

TABLE II
Influence of fillers on the physical properties of UV-curing adhesives

			Loctite 358				
Adhesive				with Aerosil		with Bentone	
Parameter			(pure)	2%	5%	2%	5%
Viscosity (η)	Pa.s	h	2.2	4.4	7.5	3.1	4.0
		1	4.0	9.0	46.0	8.0	20.0
Shrinkage (δ)	%	b	5.8	4.5	2.8	5.3	5.6
		a	6.5	5.2	4.5	5.5	6.1
Modulus (E)	MPa	1	350	400	150	500	400
		2	4	7	6	5	6
Strength (τ)	Mpa		8.7	9.6	8.3	7.6	9.2
T_g	°C		54	63	62	52	57
Coeff. of thermal expansion (α)	10^{-5}/°C	*	11.5	12.1	9.5	11.5	9.5
		**	61.3	55.3	54.2	62.5	56.5

Notes: h = viscosity at shear rate 100 s^{-1}
1 = viscosity at shear rate 1 s^{-1}
b, a = shrinkage before and after annealing
1 = at 20°C; 2 = at Tg + 50°C
T_g determined from measurement of coeff. of thermal expansion
* = α below T_g; ** = α above T_g

Table II gives the results of the determination of adhesive proprerties. This shows that the shrinkage-reducing effect is rather large for the relatively small amount of filler used. The optimum situation is achieved by Loctite 358 with 5% R202, where the shrinkage was 2.8% for the unannealed adhesive. After stabilizing, the shrinkage rises to 4.5%, caused by volume relaxation. The drawback of this approach is that viscosity is largely influenced by the addition of the filler, especially at low shear-rates; in the case of SD-2, very high viscosity levels are reached. In practice, this presented real problems for the application of the adhesive, as the required adhesive volumes are very small; 0.5 mm^3 (= 0.5 μl).

The low filler quantities did not require any additional curing time. DSC thermograms showed that the exothermic reaction and the rate of polymerization were not markedly affected. An example of such a measurement is shown in Figure 8, which shows that the peak exotherm is reached 0.5 minutes after irradiation, and that the reaction is almost complete after 1.5 minutes. Further, the fillers did

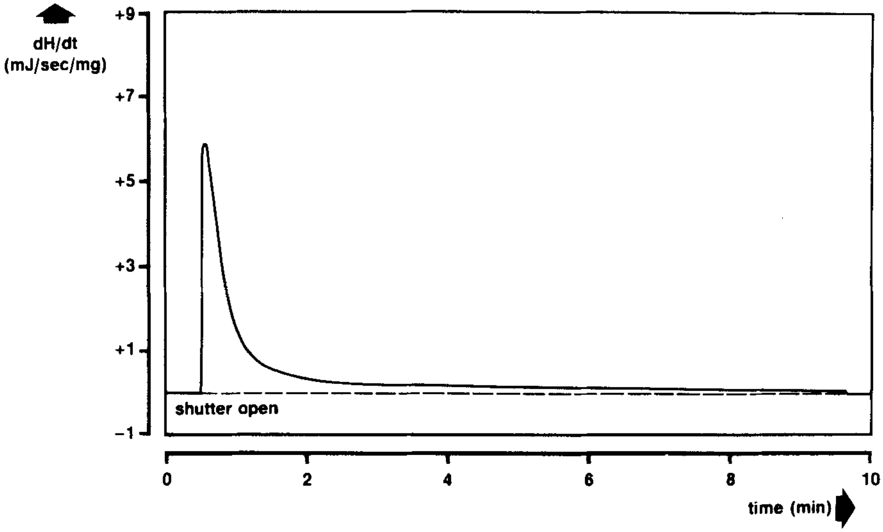


FIGURE 8 Isothermal DSC measurement of Loctite 358 at 45°C.

not have a measurable effect on some of the important physical and adhesive properties. The differences found are within the limits of experimental error.

Note that the thermal expansion coefficient of the adhesives above T_g are remarkably high. This is not yet fully understood and will be the subject of future investigations.

The use of fillers to modify shrinkage behaviour seems promising. However, zero-shrinkage adhesives have not yet been made, so modification of the adhesive is not the appropriate method to prevent displacements in the delicate direction, *i.e.*, along the optical (z) axis; it was necessary to modify the adhesive construction to meet the z direction positional and stability accuracy.

CONSTRUCTIONS

Gap Construction

In general, the gap construction, as shown in Figure 3a, is not suitable for optical light-paths because, (i) adhesive shrinkage causes displacement of the optical components; (ii) differences in the physical properties, *e.g.*, Young's modulus and thermal expansion coefficient, of the optical components, substrates and adhesive, cause bending of the components; (iii) optical components often have a semi-transparent function, or have to be mounted above an opening through which light passes; this precludes the application of adhesive across the whole of the back of the component.

At a standard gap of 100 μm a positional error of at least 5% with Loctite 358 was detected. Using a thickness of less than 100 μm, the mirrors in the model experiments became bent.

Three-dot Construction

The three-dot construction, as in Figure 3b, has proved to be suitable when rather large z displacements are allowed. The three dots have an elastic function that prevents bending of the optical components. Experiments have shown that the elastic function depends on the height/diameter ratio of the dot; *e.g.*, with Loctite 358, a dot diameter of 1.5 mm and a gap of >100 μm is necessary. However, a gap of 100 μm means a z displacement of 6 μm because of adhesive shrinkage, whereas the displacements in the same direction caused by breathing of the adhesive (thermal behaviour during the period of use) can add up to about 1 μm. The experiments have also shown that the rotational displacements (α and β) after positioning and tests are small (0.3 mrad).

Neck Construction

Figure 3c shows a construction with the plane parallel plate partly inserted in the hole. However, the small gap width (about 300 μm) does not allow easy dispensing between the wall of the hole and the plate with, as a result, "neck-forming," as represented in Figure 3c. Adjusting the optical component in the hole to its required positioning tolerances causes small differences in gap dimensions and, consequently, impermissible deviations in z, α and β.

Rib Construction

The problems mentioned above can be solved by the adhesive construction shown in Figure 3d. This shows a plane parallel plate fully inserted into the hole in the housing. The hole has mounting ribs that guarantee easy dispensing and an "unchangeable" fixing, provided the adhesive is applied as shown. This means that the adhesive must be dispensed between the upper and lower sides of the plate. Deviations from these dispensing requirements cause neck-forming and, as a consequence, unacceptable displacements and rotations along and around axes. Experiments have shown, after positioning and stability tests, z displacements $\Delta z = 0.5\ \mu\text{m}$, and rotational deviations $\Delta\alpha$, $\Delta\beta = 0.1$ mrad.

Miniaturized Optical Scanning System

It will be clear that the strength of some of these constructions is limited by the relatively small adhesive area available for bonding. However, this will never give problems with normal light-weight optical components. In practice, it was established that UV-curing adhesives enable miniaturization of the laser light-path with high dimensional stability. This is illustrated in Figure 9, which is a

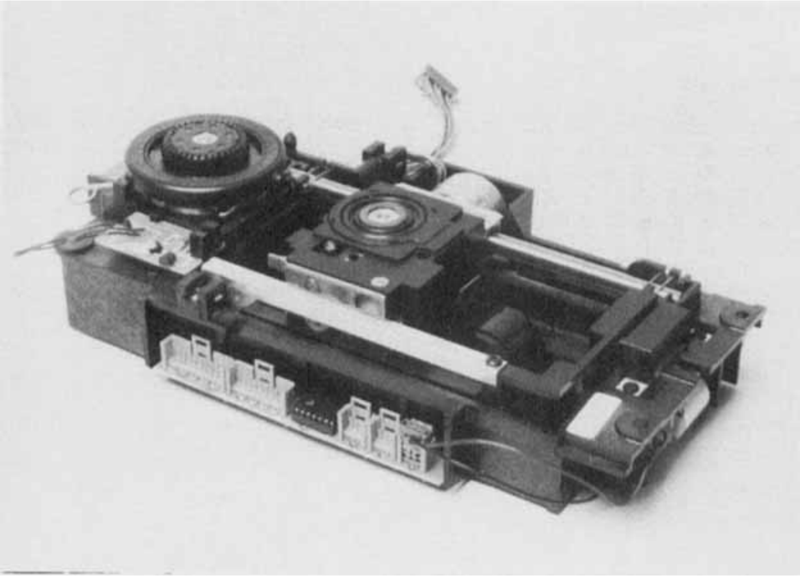


FIGURE 9 Design of the new miniaturized LaserVision video optical light-path unit.

photograph of the "new" miniaturized laser light-path unit, which is very small compared with the "old" unit, shown in Figure 2.

CONCLUSIONS

The use of UV-curing adhesives has proved to be a fastening method that enables quick and easy mounting of optical components in housings, with relatively high precision, using standard constructions such as the "three-dot" construction. For some delicate optical components with extreme precision requirements (*e.g.*, the plane parallel plate) the adhesive construction has to be modified. The rib construction has proved to be a very accurate fixing method that meets the extreme requirements, taking the sensitivity of the optical measuring equipment into account.

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References

1. H. C. Haverkorn van Rijsewijk, P. E. Legierse and G. Thomas, *Philips Tech. Rev.* **40,** 287, (1982).
2. J. G. Kloosterboer and G. J. M. Lippits, *J. Rad. Cur.* **11,** 10, (1984).
3. A. Smid, *J. Opt. Soc. A,* **A1,** 1283, (1984).
4. R. J. M. Zwiers and G. C. M. Dortant, *Appl. Opt.* **24,** 4483, (1985).
5. R. J. M. Zwiers, J. J. M. Braat and G. C. M. Dortant, *SPIE. Vol. 645–Optical Manufacturing, Testing, and Aspheric Optics,* **53,** (1986).
6. D. J. Broer and G. N. Mol, *Integration of Polymer Science and Technology,* (Elsevier Appl. Sci. Barking, England, 1986), p. 669.
7. G. W. Fulgate, *31st International SAMPE Symposium,* 1986, p. 512.