Outer Optical Elements in Optical Assemblies: Handling and Cleaning and How to Refer to Visual Damages in Use and Maintenance.

Prepared by Michael Hausner* and Avinoam Fishman (December 2023)**

Optical assembly includes in most cases outer optical element (dome, lens, or window), coated or not and it exposed to different environment conditions.

Most coatings are Anti-Reflection (AR) but can also be different depending on the purpose of the assembly in which the elements are assembled.

The purpose of the outer optical element which a part of the whole optical assembly is to determine the optical performance of the system and/or to protect the assembly's internal elements from environmental pollutants (dust, moisture, insects, bird's damages, water droplets, ice, etc.) present in the free air. These contaminants that stick to the outer surface of the outer element may impair the functioning of the element and the entire optical assembly. The amount of contamination on the surface of the external element depends on the environmental conditions to which the system is exposed, the duration of exposure, the seasons of the year during exposure (summer, winter) and the area of operation of the system (desert - dust, sea – on and below water, air – dust, birds, insects, water drops, hail, and rain in winter). Even during the storage period (not in use), the system and along with the outer element, which is a part of the system, should be kept in suitable conditions (temperature, humidity, protection from dust) to prevent damage to them.

In many cases, the user or the buyer doesn't aware of how to treat and refer to those outer elements to keep them in proper condition. In proper condition, meaning that the outer optical element doesn't hurt or reduce the functionality of the optical assembly.
But, when something happened to those outer optical elements and impurities are detected on the outer surface of the element, a cleaning process should be carried out to remove the observed impurities.

It is important to note that there are three main areas of using optical assemblies: on air (airborne assemblies: on aircrafts or unmanned aerial vehicles), on land (vehicles or fixed in one place) and on water (naval assemblies/marine vessels). And of course, in different areas, different infections and injuries appears.
So, the following article, divided in two parts, explains, and suggests what and how to do to keep the assembly in good functional condition to fulfill the tasks for which it was intended successfully.

1. Handling and Cleaning Outer Optical Elements in Use

1.1 General

The following guidelines apply to external optical components such as domes, windows, and lenses, coated or not, that are resistant to conventional cleaning agents (acetone, alcohol, soap) and assembled in optical assembly. These guidelines do not apply to optical components made of plastic materials such as Polycarbonate (PC), CR39, Acrylic (PMAA) and others.

The guidelines explain how to treat and clean external, coated, and uncoated optical components in optical assemblies after any impurities have been detected on their external surfaces. The explanation presented below will enable even those who are not skilled in this to perform their work without harming the components and functioning of the optical assembly.

1.2 During and after completion of the use

During the assembly's use, nothing should be done otherwise it may fail its use, but immediately after or at rest, the outer surface of the external optical element should be visually examined. If impurities are detected on the surface, the surface should be cleaned as explained later in paragraph 1.6. Postponing the cleaning may make it difficult to clean at a later stage and cause damage to the surface and even impair the performance of the assembly. (For airborne assemblies, visual inspection should be done only on ground after the mission is completed).

1.3 When the assembly is not in use

When the assembly is not in use or stored, it is desirable that the optical components be covered and protected to prevent any possibility of the external optical surface encountering environmental pollutants, including human finger's fats.

1.4 Safeguards

At all stages of cleaning, hand protection safeguards should be used: thimbles or gloves for two purposes: one, to protect the hands from hazardous detergents (alcohol, acetone and sometimes soap) and second, to prevent hand grease and other infections that may be on the hands from adhering to the surface being cleaned.

For safety use, see relevant MSDS/SDS for Acetone, Alcohol and Soap. It would be good if appropriate guidance is given by a competent authority on safety issues of the use of hazardous substances.
(**MSDS** – Material Safety Data Sheet, **SDS** - Safety Data Sheet).

1.5 Materials needed for cleaning

Following are the materials needed for cleaning outer surfaces of outer optical elements:

- Filtered, clean and dry compressed air,
- Blend of gentle, neutral liquid soap with distilled water (concentration up to 1%)
- Distilled water,
- Lens tissue or white fabric (only), thin and delicate,
- Cotton wool,
- Sticks wrapped with cotton wool,
- Alcohol, clean and of technical grade (Ethanol or Isopropanol),
- Acetone (Isotopic purity), clean and of technical grade,
- Fingertips (finger cots) for single use,
- Rubber gloves for single use,
- Plastic gloves (polyethylene) for single use.

1.6 Cleaning procedure

Training and experience are of great importance in the success of optimal cleaning without causing damage. It is desirable, therefore, for those who are supposed to perform this work, to receive appropriate training and certification to perform the work.

Following are the recommended steps in the cleaning process:

a) Spray filtered, dry, clean compressed air on the outer surface of the optical element to remove observed impurities: dust, water droplets and other possible debris. Try to have the spray at as small angle as possible relative to the cleaned surface.

b) If impurities remain after taking step **a)**, dip cotton wool or lens paper or fine, delicate white fabric in alcohol and wipe the component gently, in circular motions applying light pressure to remove dust, stains, fingerprints and other existing contaminants.

- Do not wipe surfaces with dry means,
- Do not reuse a used wiping device! Reuse returns the removed contaminants to the cleaned surface.

c) If impurities remain on the surface after cleaning with alcohol, repeat the process with acetone. When using acetone, take special care not to wet the rims of the item that is the belt/glue area of the item to the housing. Acetone can damage the connection when the adhesion is by RTV or the color of the housing.

d) If impurities remain on the surface after cleaning with alcohol and acetone, repeat the process with a mixture of soap and distilled water.

e) When small local infections are diagnosed on the outer surface, sticks wrapped in cotton wool soaked in one of the mentioned liquids can be used and local cleaning can be performed.

Remarks

- A cleaning kit should be stocked up in the field or when the assembly is not in use (maintenance).
- Training and certification should be carried out to the person who is supposed to handle the cleaning process.
- Reminder that this does not refer to the use of airborne assemblies during flight, but it does to airborne assemblies that are located between activities and cleaning maintenance can be carried out on the ground.

1.7 Quality Assurance

- Carrying out processes (handling and cleaning) as detailed above is intended to ensure proper performance of the assembly as defined in the appropriate documents (specifications, drawings, contracts).
- When, after performing treatment and cleaning of the outer optical surface according to the above process, any damage that noticed to the coating (peeling, crumbling, stains) or to the infrastructure of the item itself (cracks, breaks), it is necessary to act in a manner defined by the appropriate entity to examine the impact of the findings on assembly performance (deviation report, inspection with a relevant engineering body of the user or the assembly manufacturer/supplier).

2. How to Refer to Visual Damages on Outer Optical Elements in Use and Maintenance

2.1 General

As mentioned in chapter 1, there are three main areas where optical assemblies are used: on air (airborne assemblies: on aircrafts or unmanned aerial vehicles), on land (vehicles or fixed in one place) and on water (naval assemblies/marine vessels). And of course, in different areas, similar or different damages occur usually during its use but sometimes due to carelessness or misunderstanding of the sensitivity of the outer items.

This no. 2 part of the report will refer to main possible damage to outer surfaces of the outer optical element and how to treat to the observed damages. The treatment of the damaged surfaces is important to the functionality of the optical assembly and to the whole system which the optical assembly is part of it.

Just for reminding, outer optical element (dome, window, or lens) has two main aims: It may be a functional and of course it protects the inner optical and other elements of the assembly. And of course, mostly are coated (optical coatings) or uncoated.

In any case, essential information is passed through the outer optical element into the assembly and sometimes out of the assembly as well, depends of course on its use.

All products delivered to customers meet all specification requirements determined by manufacturer or by customer. This includes outer optical element, coated (mostly) or not on its surface. Both, coated and uncoated surface have some kind of “Beauty Defects”

defined by Scratch-Dig definition according to Mil-specs or by ISO standards. Those "Beauty Defects" are integral part of optic element, kind of a tolerance for optical surfaces and doesn't influence the performance of the assembly. In most cases the level of those "Beauty Defects" is far away from the upper permissible level.

During operational use, the assembly is being exposed to different environmental conditions, moderate and sever as well. As a result, some of these effects occurs on the outer optical elements. Some of these effects are expected due to the legal operational conditions of the assembly due to its intendent use but, some of it is due to incorrect, wrong, not cautious, or sloppy use. Sometimes due to luck awareness to the sensitivity of the outer optical element and optical coating on the outer surface and its importance to the functionality of the assembly.

Those changes in the outer surface of the outer optical element visually observed. In easy cases, even they are deviated from the legal Scratch-Dig definition, they are Cosmetic Defects ("Beauty Defects") and do not impact on the functionality. But, in other case, the wear (damage) is severed, very sever, and impact the functionality of the assembly and its use.

2.1.1 General Requirements for Outer Optical Elements

The requirements for the outer optical elements are specified in production files (drawings, specifications) and established by the optics designer according to the assembly needs. Those requirements include dimensional parameters, optical requirements (transmission, reflection, and others), coating durability requirements (humidity, temperature, adhesion, abrasion, and others) for coated elements and cosmetic requirements ("Beauty Defects") represented by Scratch-Dig definition according to Mil-Specs or ISO Standard.
Those cosmetic requirements ("Beauty Defects") are valid during all steps including manufacturing, mounting, functional and visual tests, finally, packing and delivering to customer's destination. Contract's obligation for functionality of the assembly includes of course everything referring to the outer optical elements according to the parameters covered in drawings and/or specifications. Duration of manufacturer's warranty is according to the contract's obligation.

Things to take in account.

- Existence (or not) of maintenance contract between the user and the supplier/manufacturer,
- If there is no maintenance contract between the user and the supplier/manufacturer, how old is the assembly and the cost of maintaining it,
- Severity of the damage to the outer optical element and its influence on the functionality on the assembly.

2.2 What kind of damages?

During the use of the assembly by customer/user (operation, storage, handling, and transportation from one place to another), the outer optical element can be exposed to sever environmental conditions which sometimes are beyond the condition that are specified in the drawing and specification because of disobedience to the instructions of normal operation.

What kind of environmental conditions? As mentioned before, there are three main areas where optical assemblies are used: on air (airborne assemblies: on aircrafts or unmanned aerial vehicles), on land (vehicles or fixed in one place) and on water (naval assemblies/marine vessels). So, as some of the environmental conditions are different and some are similar, the following damage conditions on outer surface of outer optical element may occur:

On air (airborne assemblies: on aircrafts or unmanned aerial vehicles)

- Damage from impact by sand grains and dust particles,
- Damage from impact by rain drops hail,
- Damage from impact of flying birds and bugs,
- Damage caused due to high-speed flight through clouds having water drops and ice flakes,
- Damage caused due to high-speed flight through desert areas having sand grains and dust particles,
- Damage caused of adhesion of various kind of dirt like oil, dust, mud, water spots and else to outer surface of optical element,
- Damage caused by operators due to non-cautious handling, unawareness, lack of training, or improper cleaning and handling of the element.

On land (vehicles or fixed in one place)

- Damage from impact by sand grains and dust particles (high impact in desert areas),
- Damage from impact by rain drops and hail,
- Damage from impact of flying birds and bugs,
- Damage caused of adhesion of various kind of dirt like oil, dust, mud, water spots and else to outer surface of optical element,
- Damage caused by operators due to non-cautious handling, unawareness, lack of training, or improper cleaning and handling of the element.

On water (naval assemblies/marine vessels)

- Damage from impact by sand grains and dust particles,
- Damage from impact by rain drops and hail,
- Damage from impact by salty sea water,
- Damage from impact of flying birds and bugs,
- Damage caused of adhesion of various kind of dirt like oil, dust, mud, water spots and else to outer surface of optical element,

- Damage caused by operators due to non-cautious handling, unawareness, lack of training, or improper cleaning and handling of the element.

All defects generated as result of the above reasons are detected and diagnosed first by visual inspection (looking with naked eye). The diagnosis includes evaluation of what kind of a damage exists and whether the damage is to the coating (of coated surfaces) and to the raw material of the element as well.

After treating and cleaning the outer surface as has been described in Section 1 and still some kind of defects remain on the outer surface, the decision should be taken for next step.

Typical damages on outer optical element remain after treating and cleaning.

- Large or small cracks,
- Scratches and scraps (tiny and dense scratches) on coating (if exist) and/or on substrate,
- Digs (individual or multiple on large area) on coating (if exist) and/or on substrate,
- Breakages,
- Coating peeling if exist.

Possible impact of the above defects on outer optical element on assembly's performance.

- Decrease of performance up to complete failure of the assembly and its mission,
- High probability to failure's occurrence in the future (functional and damage to internal elements) and failure of the assembly and its mission.

So, what is the next step?

The decision of the next step referring to the finding are depending on the findings and the functionality of the assembly. The steps should be taken according to procedures of the user. Damages occurs due to legal use do not cover usually by the contractual liability so the relevant authority should decide how to handle with the problematic element. It should take in account the following matters:

- Is there a maintenance contract with the supplier/manufacturer of the assembly?
- Is there alternative assembly that may be used?
- How old is the damaged assembly?
- What is the price for fixing the assembly by replacing the damaged element?
- How critical is the necessity of the assembly for the mission?
- Does the observed damage degrade assembly/system performance?

Many questions, and what is the answers or suggestions?

Practical recommendation on how to refer to defects on outer surface on outer optical elements of optical assembly.

There is no way yet to determine quantitative criteria for acceptance or rejection of outer optical element due to huge number of defects on its outer surface (different types,

shapes, sizes, and quantities). Therefore, the criteria during or after the use of the assembly, and during its maintenance, is usually qualitative and based on consideration of the user or the inspector and of course on the functionality of the assembly despite the damages on the outer element and its outer surface. If there is no decrease on the functionality of the assembly or even there is small decrease, but the assembly is function in acceptable way, then the consideration and decision as detailed below can be taken.

Recommendation for decision by the user or customer of the product

- **Dirt** – must be removed, even before functional testing and then the outer surface should evaluate for its severity. If the assembly functions well, Use-As-Is.
- **Coating peeling** – are they big or small? Their influence on functionality in I.R. (Infra-Red) region is higher than on VIS (Visual). If the assembly functions well, Use-As-Is, if not, mostly in I.R. region, don't Use-As-Is.
- **Scratches and scraps** (tiny and dense scratches) – mostly do not degrade the functionality of the assembly. If the assembly functions well, Use-As-Is.
- **Digs** - mostly do not degrade the functionality of the assembly. If the assembly functions well, Use-As-Is.
- **Small cracks** – typically appearing around digs or are part of scratches or independent as well. mostly do not degrade the functionality of the assembly. If the assembly functions well, Use-As-Is.
- **Large crack** – might cause a serious damage to the outer optics element and even to the inner parts of the assembly after the crack cause to a breakage to the element. Do not take a chance and don't Use-As-Is.
- **Breakage** - might cause a serious damage to the outer optics element and even to the inner parts of the assembly. Do not take a chance and don't Use-As-Is.

Right consideration is very important to the ongoing function and use of the assembly and to the steps for its maintenance including logistical and economic issues.
For example: coating peeling from Silicone outer I.R. surface can cause a significant reduction in system performance but very little impact performance on K5 (of SCHOTT) window in VIS region.

References in technical literature regarding this article and "Beauty Defects".
Very poor literature dealing with matters of this article. It can be understood due to decisions relevant to different organizations or users and its procedures of what and how to treat damages occurred to outer surfaces of outer optical elements during operation. We couldn't find any.
But there are many articles dealing with Scratch-Dig issues, but they refer mostly to new, not used elements and the Scratch-Dig number (or letters) are defined in drawings of each element.
Following are the relevant Mil-Specs and ISO standard dealing with Scratch-Dig issues:

- **MIL-PRF-13830B (1997)** - "Optical components for fire control instruments; General specification governing the manufacture, assembly, and inspection of".

- **MIL-C-675 (1980)** - "Coating of glass optical elements".
- **MIL-C-48497 (1980)** - "Coating, single or multilayer, interference, durability requirements for".
- **MIL-M-13508C (1973)** - "Mirror, front surfaced aluminized, for optical elements''.
- **MIL-C-14806A (1969)** - "Coating, reflection reducing for instrument cover glasses and lightning wedges''.
- **ISO 10110-7 (2017)** - Surface imperfections.
- **ANSI/OEOSC OP1.002-2017** Optics and Electro-Optical Instruments - Optical Elements and Assemblies - Surface Imperfections.

But very important line in **MIL-PRF-13830B** says: "Defects not otherwise covered in this specification, which will not impair the performance of the finished instrument, shall be permissible. Whether a particular defect shall be permitted will depend on the location of the element in the finished optical system. Defects in element not near a focal plane are not as important as in elements which lie in or near a focal plane…".

And there are some important articles referring to "Beauty Defects" for optical surfaces:

- **"Scratch and Dig standard revisited"** by **Matt Young**. Published in "Applied Optics"/Vol. 25 / 15 June 1986.
- **"Common sense in optical specification"** by **N. Balasubrmanian** and **M. Harcher**, The Institute of Optics, University of Rochester, Rochester, New York. Published in Society of Photo-Optical Instrumentation Engineers, Vol. 54, 1974.
- **"Specification and Tolerances, Optical Style-A Company"** by **Warren J. Smith**, Infrared industries, Inc., P.O. Box 989, Santa Barbara, CA 93102. Published in Optical Engineering, September-October 1976 / Vol. 15 No.5.
- **"A Prudent Approach to the Design of Optics"** by **John Plummer** and **Walter Lagger**, Plummer Precision Optics, Pennsburg, Pennsylvania. Published in Photonics Spectra, December 1982: **"A good rule of thumb to remember is that optics are made to look through, not in"**.
- **"Inspection of High-Volume Laser-Quality Optics"** by **Gih-Hong Chen** and **Gary DeBell**, Spectra-Physics, Optics Division, Mountain View, CA 94042. Published in Workshop on Optical Fabrication and Testing" – Sponsored by Optical Society of America.
- **"Optical Component Specifications"**. Published in 'The Photonics Design and Applications Handbook, 1987.
- **"Beauty Defects"** according to MIL-STD-150A, 1959, **"Photographic Lenses"**, paragraph 3.8.
- **"Beauty Defects"** according to **"The Photographic Dictionary"**, 1987.

For additional information, see **Scratch & Dig** chapter on https://www.michael-hausner.com address.

Summary

The above information is based on our knowledge and experience in long years of inspection of optical elements and everyone in the optical industry can use this information for his use as needed.

Comments to this article are welcome to the following email: hausner555@gmail.com

Additional information on optical subjects you can find on:

https://www.michael-hausner.com

*__Michael Hausner__ has about 40 years' experience in inspection and tests of optical elements: incoming and at the source of production, review of optical elements suppliers, writing procedures for optics inspection, handling of nonconformance optical elements and corrective actions, consulting, and training for inspection of optical elements.

**__Avinoam Fishman__ has about 50 years' experience in inspection and tests of optical elements: incoming and at the source of production, review of optical elements suppliers, writing procedures for optics inspection, handling of nonconformance optical elements and corrective actions, consulting, and training for inspection of optical elements.