Barco

How to keep your digital projector performing optimally over its lifetime

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INTRODUCTION

In a previous whitepaper [1], we talked about optical efficiency in digital cinema projectors and how to get maximum – optical – performance out of your projector. That paper focused on projection design parameters and, therefore, it implicitly compared new projectors to new projectors – or the situation on Day 1.

This whitepaper builds further on that previous paper by explaining what happens *after* Day 1. That is, what is your projector's optical performance over time as you use it for hours, days, weeks and years? What factors determine a projector's light output, and how can we work with them to optimize the projector's performance?

In addition, this paper expands the scope of our discussion to digital projectors in general (not only digital cinema projectors). Many of the factors that we discuss are relevant to any digital projector setup.

1. Scope

This whitepaper only discusses **optical performance over time**: that is, parameters that can be measured on-screen (via the light leaving the projection lens). We will not cover electrical, mechanical, software, or other parameters (even though – as we will see – they can impact the optical performance). We will also focus on **parameters that evolve gradually over time** (over the lifetime of the projector or shorter term). We will not cover effects that have an immediate - mortal – effect on the projector's performance (e.g. bulb explosions), because:

- these are purely statistical variables, and it's impossible to predict when and how often they will occur.
- there is no behavior to describe, there are few preventive measures.
- their occurrence is typically very rare.

In all the effects we describe below, the projector inherently continues to work, but there is a change in its optical behavior over time. Some of this change will be visible, measureable and/or compensative; and some will not.

2. Terminology

Discussions about a projector's optical performance contain a surprisingly large amount of terminology: 'typical light output' vs. 'minimal light output', 'calibrated lumens' vs. 'nominal lumens', 'warranty lifetime' vs. 'estimated average expected life', and so on. In this whitepaper, we restrict ourselves to relative performance: how brightness, color, contrast, etc. evolve over time, compared to the situation on Day 1. We use terminology like 'light output', 'lumens' and 'lifetime', but in a general sense, not in a way that requires exact definition or quantification.

However, in real-life discussions about projector performance, it does come down to these exact definitions and quantifications. We want to emphasize the importance of using correct and accurate parameters when analyzing a projector's performance over time. Only an apples-to-apples comparison leads to correct conclusions. Here are some typical examples:

- *Nominal vs. calibrated lumens*: during installation (and throughout its lifetime) the light output of a digital projector is always geared to meet the specifications of the market it is used in. Typical specifications relate to white point and color gamut (usually, all of these are quantified in x and y color coordinates). This calibration of color parameters is always compensated for by a reduction in total light output (quantified in lumens). By 'nominal' lumens, manufacturers mean the amount of light coming out of the projector as is, without any calibration. Color can be completely off, but light output is typically at its maximum. This is not how the projector will perform in the field (assuming that you calibrate it to the specifications that apply to the field of application). By 'calibrated' lumens, manufacturers mean the total light output when the projector is calibrated to the application specifications. This number is always lower than the nominal lumens. When analyzing your projector performance over time, be sure to measure and refer to the correct metric.

- *Lifetime vs. warranty lifetime vs. estimated average expected life*: this parameter is typically used for the lamps that are the light source for the projector. This is independent of the type of lamp that is used (UHP and Xenon are the most common). With regard to 'lifetime', a projector lamp is considered to be at the end of its life when: either it malfunctions completely (explodes, no longer lights up, flickers visibly, …), or its light output drops below 50% of the level it had when it was new. The lifetime that a lamp manufacturer quotes for its lamps is an average statistical value: usually the point in time when 50% of a lamp population fails (completely or drops below half of the maximum light output). Therefore, some lamps reach their end-of-life sooner, others later – there is no guarantee regarding this. 'Warranty lifetime' builds in some guarantee (e.g. you receive a new lamp, free of charge, if the original lamp fails early). You will understand that, in order to build in this guarantee, the manufacturer has to take some safety margin, and so the 'warranty lifetime' is shorter than the 'lifetime'. This safety margin is well known in the market, and people started using the lamps longer than the warranty lifetime (at their own risk). Some projector manufacturers noticed this and added an 'estimated average expected life' to their lamp specs. Although this parameter might look attractive because it's longer than the warranty lifetime, it is again a purely statistical parameter, with no guarantee if the lamp should fail. Again, when analyzing your projector's performance over time, be sure to consider the correct end-of-life parameter for your lamp. Also, when comparing manufacturers: be sure to compare apples to apples.

PARAMETERS THAT IMPACT LIGHT OUTPUT OVER TIME

1. Lamp

As stated above, UHP and Xenon lamps are most commonly used in digital projectors. The 2 lamp types work on the same principles: they are filled with gas vapor (Mercury in the case of UHP, Xenon in the case of Xenon lamps), and they have 2 electrodes placed closely together to form an arc of light when the correct voltage is applied.

In order to drive projectors that emit thousands of lumens, these lamps generate a multitude of that – all from a very narrow gap between the electrodes. Understandably, the load on the lamp's components from the internal temperature and the voltage is huge. The basic laws of physics lead to the fact that a lamp cannot keep emitting its maximum light output indefinitely. For example, the electrodes - even though constructed from specifically designed metal - begin to erode at their tips, which impacts the length and stability of the arc. In addition, as the electrode's material evaporates, some of it condenses on the lamp as a black residue. The impact on the lamp's light output is two-fold (although the magnitude of impact is different for the 2 types of lamps):

- *Reduced light output (lumens)*: the total amount of light emitted from the lamp falls off. As stated above, the point at which it reaches 50% of its original output is considered to be the end of its lifetime. As the projector can be regarded as a (very intelligent) filter on the lamp's light, it is clear that less light from the lamp means less light from the projector. However, there is a way to optimize the projector's performance as the lamp's light deteriorates. This has to do with how the lamp's arc is focused on the compact projector optics. In a well-designed projector, the optical path is optimized to fit the lamp’s arc (which helps make the total setup compact and efficient). However, this means that, as the lamp’s arc changes, the relation between arc and projector optics is no longer optimal. With Xenon lamps (but not UHP lamps), this can be (partially) compensated for by physically adjusting the lamp’s position (and that of its arc) to again match the interface with the projector’s optics. This is the reason that well-designed projectors have an adjustable lamp housing. It is also important to understand that the point at which this 50% light output is reached depends on how it is measured: in UHP lamps, it is typically measured (and specified) on a stand-alone lamp (not built into the projector); in Xenon lamps, it is typically tested and measured in a real-life setup. This is an important distinction, because the arc shift described above contributes to the lamp’s natural decay and so the 50% point is reached sooner. However, when this measurement is taken outside the projector, the arc shift is not taken into account, which leads to an unrealistically high value. Be sure to ask your supplier how these values have been measured and quantified.

- *Changed color point*: the color coordinates are not exactly the same across the length of the arc. This depends on the temperature of the arc, which varies as you move closer to, or further from, the electrodes (these differences are very small, but measureable). As stated above, the alignment between the arc and the projector optics is very accurate. This means that, as the arc changes with the lamp’s aging, the focal point of the projector with respect to the arc changes too, with the possibility that it moves to a different position (i.e. color point). Here again, an adjustable lamp housing with a Xenon lamp can help (partially) solve this.

Another consequence of the high temperatures and pressurized gas inside the lamp, is that no two lamps behave in exactly the same way. There is always some spread on the lamp’s light output: plus or minus 10% is a realistic spread. This means that, if the manufacturer specifies a projector at X lumens and you put in a brand-new lamp, it could very well be that you get only 90% of the expected light output. Know that this could be due to the spread on the lamp’s parameters – it’s not necessarily a symptom of projector aging.

The difference between nominal and calibrated lumens (see above) is also impacted by the type of lamp. The spectrum of a Xenon lamp is broad, and the nominal white point lies close to 6500K; while that of a UHP lamp is more peaked and is bluish white. This means that more compensation and calibration is needed to get from nominal to calibrated lumens on a UHP-based projector. The difference between these 2 specifications will be greater.

All in all, the lamp's behavior causes the greatest variations in the projector's performance over time (down to 50% when calculating to the lamp's lifetime). Fortunately, the drop in light output can be partially corrected (by adjusting the arc position) or fully corrected (by installing a new lamp).

2. Dust

As stated in the previous section, lamps run at high internal temperatures in order to generate the high lumens for the projector. This high temperature is released into the projector housing. In order to keep the projector cool (see next section for why this is important), air is blown through the device (sometimes in combination with water- and/or electronic-cooling).

This air is the normal ambient air that is taken from the room and blown through the projector to remove the heat from the housing. However, the dust and small particles in the ambient air are sucked into the projector as well. When not properly filtered out, dust can lead to:

- Visible artifacts in the image: when present in the optical path, a dust particle can act as a smudge on your (sun)glasses. Given the fact that a projector magnifies to the size of the screen, a 100 micron particle could appear as a very big and very visible artifact on-screen.
- Reduced contrast ratio: the artifacts described above will only occur when the dust particle is present in an image plane (when it is in focus). If this is not the case (for example, the particle is somewhere along the border of the optical path), the impact will be biggest on the contrast ratio: that is, light is scattered off the tiny particle and sent in directions it's not supposed to go. This excess light has the biggest impact on the black off-state in which you ideally want 0 lumens. Scattered light from internal dust particles increases the light levels of black content, reducing the contrast ratio.
- Mortal failures: the 2 examples above discuss the impact of dust on optical components. However, it can also impact electronic or mechanical components, typically leading to mortal failures instead of a gradual decay in performance. Dust can clog electronic connectors, or even jam fans.
- Overheating: we discuss thermal load in more detail in the next section, but it is important to remember that dust

can contribute to overheating (for example, when dust jams a fan). A more common example is when filters are not maintained or cleaned regularly and become clogged with dust. In this case, the throughput of fresh cooling air is reduced and overheating can occur. It is also possible for dust to create a thin insulating layer inside the projector, preventing efficient convection.

It is clear that keeping dust out of the projector is crucial. This might cause extra work, but the best way to prevent dust on the inside is to prevent dust on the outside. This means cleaning your projection booth regularly, not blowing dust or smoke directly at the projector, cleaning external dust from the projector and filters, … All service manuals provide guidelines on how often to do this.

Of course, a well-designed projector also has some tools on board to prevent dust:

- External filters: these filters form the first boundary for the ambient air that is sucked into the projector. Designing them is always a balance between cost, ease-of-use, required throughput, and so on. The external filters of well-designed projectors are adapted to the field of use (they are not simply standard off-the-shelf paper filters).
- Sealing of crucial areas: no external filter can keep out 100% of the particles in the ambient air. So it's crucial to build in extra dust protection for the most critical components in the projector. This critical zone is where the image is formed: around the prisms and the active chips (DMD, LCoS or LCD). The problem is that sealing off an area usually makes it more difficult to keep that area cool. Barco has a patented technique for sealing and cooling the engines of its projectors.
- Optimal use of liquid and electronic cooling: as stated above, air cooling is only one way to keep the projector and lamp from overheating. Liquid and electronic (Peltier) cooling are more efficient, but more complex. Adding them to air cooling reduces the amount of air throughput that is required, thus reducing the impact of dust. A well-designed projector combines all these cooling techniques to keep each component at its ideal temperature, while reducing total air throughput and keeping complexity manageable.

As stated above, some consequences of dust are gradual, and others are fatal immediately. With regard to the optical performance of digital projectors, dust will cause a gradual degradation of light output. This can be visible as (an increasing number of) artifacts in the image, reduced contrast ratio, and/or reduced light output. Of all the factors discussed in this white paper, dust is probably the easiest to combat in order to get the most out of your projection equipment. Note that dust on the projection lens can also cause similar problems, which can be solved very easily by cleaning the lens surface (as described in the service manual).

3. Thermal load

Even when the cooling system is working perfectly, some parts of the projector are exposed to temperatures that easily exceed 100°C. Almost all of the projector’s components are built to last for the projector’s lifetime at their specified temperature. However, when the internal temperature increases (due to dust or a rise in the ambient temperature), the components are exposed to higher thermal load. Although the consequences of higher thermal load can be gradual or immediately fatal, we discuss only the ones that lead to gradual degradation in this white paper:

- Structural deformation: materials impacted by heat can deform and change shape, size or format. In theory, this can happen to every projector component; but in practice, the risk is highest for thin layered structures that are exposed to the highest temperatures. The reflector of the lamp housing is such a critical component. When not designed well, its surface will deform and become unsmooth due to the thermal load. This impacts the accuracy with which the arc light is focused into the optical path (see above). The consequence of this gradual deformation is a gradual reduction in light output. However, this cannot be compensated for by adjusting the lamp.
- Discoloration: in this case, the size and shape of the component does not change, but its color does. A well-known example is oil browning in a frying pan when exposed to excessive heat. The projector’s case is comparable: the artifact is a yellowish/brownish coloration, and the impacted materials are also organic. These materials might be plastics (even though all well-designed projectors use specially selected glass in their optical path), but more commonly they are the liquid crystals inside an LCoS- or LCD-based projector. These liquid crystals are organic oils with some special opto-electronic properties. For this reason, DLP technology is the preferred choice for high-brightness projectors in which the thermal load is greatest.

As stated above, even when the cooling mechanisms are working perfectly, the thermal load on the projector is never zero. However, all components in a well-designed projector are specified to withstand normal thermal load over the projector's lifetime. One way thermal load is minimized in these projectors is through built-in infrared filters that prevent these wavelengths from propagating in the projection engine. Although they do not contribute to thermal load, the ultraviolet wavelengths in the lamp's spectrum can also cause discoloration. So, to complement the infrared filters, well-designed projectors also use UV filters.

4. Ambient parameters

All of the parameters impacting a projector's light output that we've discussed so far are directly related to the projector. This seems logical, but in practice we never measure lumens coming directly out of the lens. We always measure light reflected from the screen (luminance). Between the lens and the luminance meter, there are parameters that impact performance. Some of these parameters also undergo gradual degradation, which leads to a perceived degradation of light output. The most common parameter is the projection screen, which becomes dirty over time, thus losing some of its reflective properties. In other setups, the porthole window might block more light than expected.

When analyzing your projector's performance, be sure to take the effects of these parameters into account. Or even better: eliminate them from the equation by, for example, removing the porthole or replacing them by a calibrated reference (white patch instead of screen).

CONCLUSION

The light output performance of a digital projector can be expressed by a variety of metrics: brightness, color, contrast, uniformity, … Under the influence of internal and external factors, all of these qualities can degrade over time. Some degradations are (partially) reversible, others are not; some can be prevented, others cannot. It is important to understand where degradation can originate to be able to analyze the root cause when it occurs. This also helps make an accurate apples-vs-apples comparison.

Furthermore, the importance of calibration and correct setup is also important with regard to measurement devices. Only a well-calibrated meter guarantees the correctness of your measurements, and the conclusions you draw from them.

REFERENCES

[1] Tom Bert, Rik Defever, Peter Janssens and Nico Coulier; "*Optical efficiency in Digital Cinema projectors*"; Downloadable at www.barco.com