CD Production: reducing costs by improving quality

Dr Leonhard Schwab (CTO and co-founder, dr.schwab Inspection Technology GmbH) explains how inspection systems can give the CD replicator a competitive edge.

Introduction

The Compact Disc – now celebrating its 20^{th} anniversary – has been a success story since day one. During the past twenty years, new formats with

- higher capacity (DVD, Blu-ray Disc)
- more layers (dual layer and/or dual sided DVD)
- recordable or rewritable data layers (CD-R, CD-RW, DVD-R, DVD±RW)

have been developed, but despite these innovations the pre-recorded CD-Audio and CD-ROM still have a promising future as mass products.

The basic CD manufacturing process is well developed. Nowadays, the primary challenge in CD production is **cost reduction**. Cycle time must also be reduced, while the current tendency towards shorter production runs demands more frequent changes of stamper.

A frequently asked question is whether quality control is still necessary for such a well-established process. However, it is more important to recognise that efficient process control minimises the start up time after a stamper change, and stabilises the production process by timely adjustments to keep the process within specification. Thus stamper utilisation can be maximised, while rejects and material waste are minimised.

Stated simply, efficient process control leads to higher yield and higher profitability.

Process Stability and the Quality Function

Schwab emphasises that only a stable process enhances yield by improving quality and reducing costs. “The traditional view is that higher output can only be achieved by compromising quality standards. This view is based upon the philosophy that manufacturing quality product means simply throwing away inferior product, thereby decreasing productivity and increasing manufacturing costs.”

He continues: “However, manufacturing quality product does not necessarily conflict with the goal of reducing costs. This can be understood by considering the **quality function**. Quality cannot be described simply by a pass/fail decision: 100% quality if the deviation from the target is within the specified limits, 0% quality otherwise. Instead, quality is a continuous function of the deviation from the target value. Any deviation from the target value means a loss of quality, even within specified limits: products close to the specification limits have a poorer quality than those close to the target value, while products outside the specification limits have an unacceptable quality. Observing this quality function in more detail can be used to control - and improve - quality **within** the process window. Because this control is performed within the process window, quality is improved and there is no decrease in yield.”

Looking at yield is one point. For an established CD or DVD process it is possible to achieve a yield of 95% to 98%. This means that the potential for saving costs by increasing yield is very limited. However, as Schwab points out, there are other factors that may make a larger contribution to cost savings.

“By applying the quality function it is possible to reduce the time necessary for the pre-run to an absolute minimum,” he says. “This means that the overall utilisation time of the line for production can be increased. Similarly by controlling the quality within the window of the running process, materials such as the stamper or sputter mask and target can be used much more efficiently.”

To control manufacturing within the process window, it is essential to use inspection equipment which covers every process step with a resolution and sensitivity that is far higher than the specified limits. Defects and process deficiencies must be classified accurately and quickly – well within the cycle time - to avoid introducing delay.

The Quality Function in CD Replication

By way of example, consider a busy CD replicator in today's competitive market, whose goals are to maximise productivity, reduce manufacturing costs and satisfy customer demand for quality product.

The CD replication process can be divided into three stages:

- start-up phase after a stamper change
- moulding
- finishing

and the key factors affecting quality examined for each stage in turn.

Start Up Phase

After a stamper change, only a small number of simple adjustments are necessary. However, these are vitally important, and prerequisite for quality. If any of the following parameters are out of specification, the complete production run will be out of specification:

- eccentricity
- thickness
- parallelism

Eccentricity is the offset of the centre hole of the disc relative to the centre of a circular track on the disc. This deviation may be caused by eccentricity of the stamper itself or by inaccurate positioning of the stamper in the mould.

Parallelism refers to the geometric relationship between stamper and mirror, and affects the uniformity of substrate thickness across the entire disc. If not adjusted correctly, the substrate has a wedge-shaped section with an intrinsic weight imbalance, resulting in an unplayable disc.

Moulding

At the moulding stage, it is important to balance settings and monitor stamper wear, and to optimise quality within the process window. Key parameters are:

- flatness
- birefringence
- pit replication

If parameters are running out of specification at this stage, it is impossible to compensate further down the line (with the exception of tilt – see ***Finishing***, below). However, process correction is possible: ideally, the process should be corrected before the parameter runs out of specification, avoiding any reduction in yield.

Throughout the process, various production operations are competing with each other and with cycle time. A careful balance is required: mould temperature, melt temperature, injection speed etc must be controlled simultaneously so that each is tuned to give the best possible performance without compromising the others.

For process optimisation it is not sufficient simply to look at the minimum and maximum values of a particular measured parameter of a disc: it is essential to consider the distribution of all results simultaneously across the entire disc. The shape of the measurement distribution provides valuable information about key factors affecting the process, especially when the distribution displays some form of symmetry.

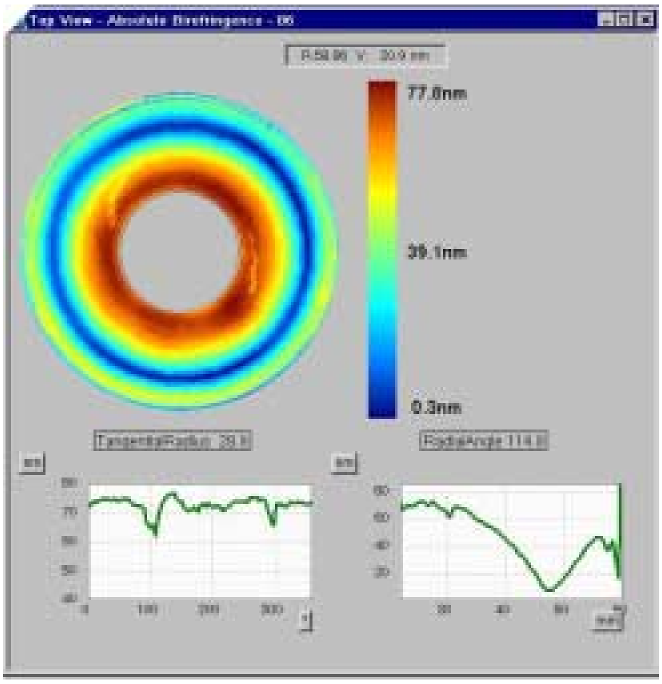

Fig 1: Birefringence – cold slugs

For example, **birefringence** typically shows rotational symmetry, which is due to the symmetry of the replication process. Any deviations from this symmetry - even if they are smaller than the specified limits of 100nm - indicate process deficiencies. One frequent problem is so-called “cold slugs” which appear as localised spots or lines in birefringence measurement (Fig 1). Their occurrence indicates that there is some residual or cold polycarbonate material in the nozzle. It can be avoided by cleaning the nozzle or by increasing the nozzle temperature.

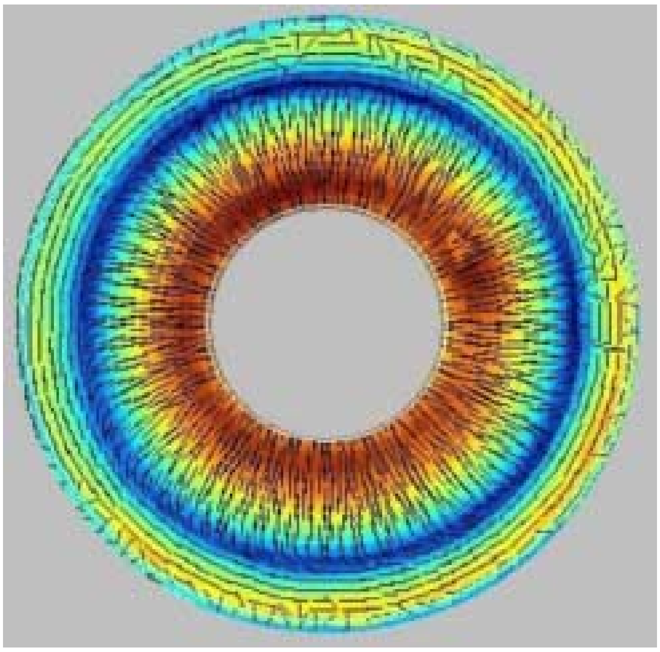

Fig 2: Birefringence - orientation

Birefringence is characterised by its value and by the orientation of its axis. Although in the red book only the acceptable value is limited, the birefringence orientation can be used as a sensitive indicator of inhomogeneities in the moulding process. Usually the axis of birefringence is orientated radially at the inner diameter and tangentially at the outer diameter (Fig 2). Any deviation from the radial or tangential orientation shows that the filling process of the cavity is insufficient.

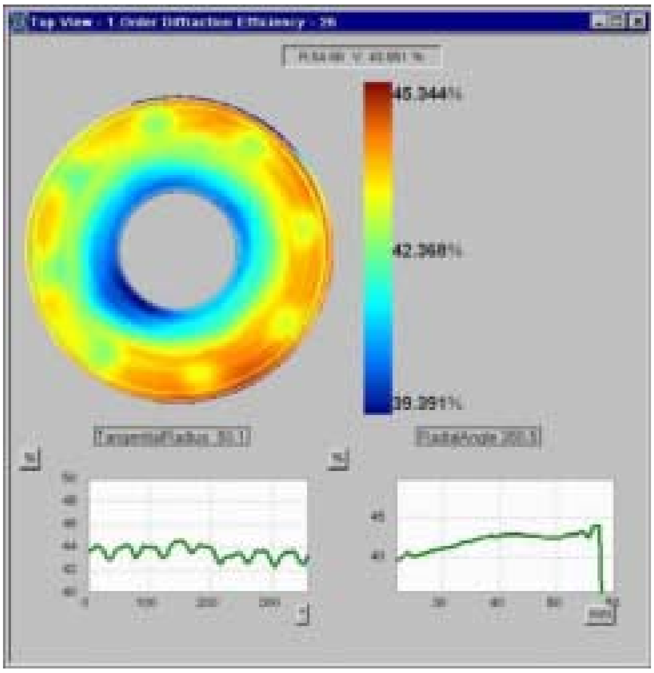

Fig 3: First Order Diffraction

First order diffraction is a quantitative measure of pit replication, which in turn depends strongly on moulding parameters: in particular, melt temperature, injection speed and temperature distribution in the mould. In Fig 3 we can see three different contributions to pit replication. Firstly, an increase of diffraction intensity from inner to outer diameter, caused by the variation of injection speed with radius. Secondly, there is a gradient from left to right which indicates a corresponding temperature gradient in the mould. Finally we can see eight-fold symmetry of cold spots at the outer diameter that are caused by the temperature and flow distribution in the nozzle.

All these variations are small and acceptable: the important point is that each individual contribution can be visualised quantitatively and controlled by individual process windows. Therefore the sensitive balance between each other and with respect to other properties can be maintained.

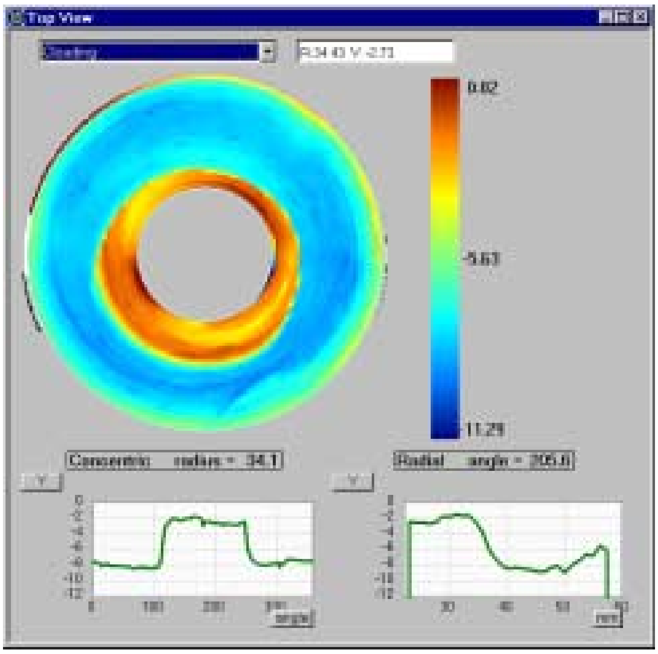

Fig 4: Clouding

Clouding is caused by incorrect separation of the substrate from the stamper. It can barely be detected by the human eye on the substrate, but after sputtering it appears as different grey shades. It cosmetically unacceptable and may cause jitter problems especially when there are sharp transitions along the track of the disc. Ideally, clouding should be detected at the moulding stage. By comparing the plus and minus first order diffraction it is possible not only to identify clouding very sensitively but also to classify it quantitatively as acceptable or not (Fig 4). Clouding can be avoided by reducing the tolerances in the mould or by reducing the mould temperature.

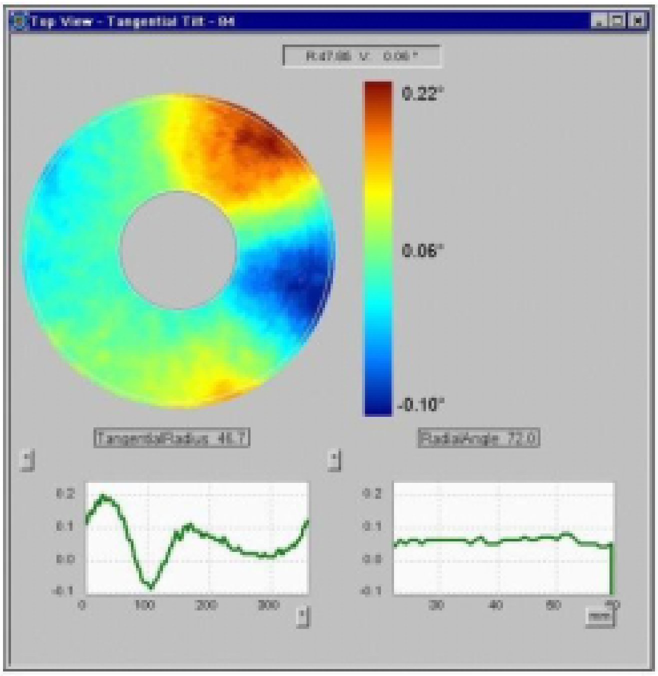

Fig 5: Tilt

As a final example we consider **tilt**. The primary cause of radial tilt (dishing) is different temperatures in the two halves of the mould. A tangential variation (Fig 5) indicates a temperature gradient in one part of the mould or a strong inhomogeneity within the cooling station.

Competent off-line inspection equipment is essential for process optimisation. When measuring a sample disc, the substrate must be allowed to stabilise and should be tested at the correct temperature for the results to be valid. Measuring a disc taken straight from the line – at much higher than room temperature – will not generate meaningful results; any changes based on such measurements will de-tune the process.

Finishing

At the finishing stage, cost reduction can be achieved by maximising target lifetime and optimising lacquer thickness and homogeneity to and minimise waste. The following parameters need to be monitored:

- sputtering
- lacquering

Sputter layer thickness usually shows a sharp drop at the inner and outer diameters of the disc. By continuously monitoring the complete thickness distribution during the manufacturing process the target can safely be used to its maximum lifetime.

Lacquer shrinkage causes tilt, and is detrimental to quality. **Lacquer thickness** and **thickness profile** can be optimised - depending on the lacquer shrinkage characteristics for the process - for the most cost-effective use of material.

It is possible to use lacquer shrinkage to compensate for tilt produced during moulding, a fact which is exploited in some replication lines. To produce a finished disc of optimum quality there must be a corresponding shift in the process window – and a high degree of process awareness - at moulding stage.

Conclusion

Although CD replication is an established process, application of the quality function concept will reward the replicator with increased productivity and cost-effectiveness through improved quality.

The concept is based on the following principles:

- Every process step must be monitored and adjusted continuously
- Every disc property must be measured accurately, at the correct temperature
- Distribution of measurement results must be monitored across the entire disc: shape and symmetry help identify process characteristics
- Process statistics are used to detect drifts and trends: corrective action is taken before the process runs out of control.

Schwab comments: "By recognising that quality is more than simply a pass/fail issue, the replicator can make real improvements to his productivity. We offer a range of inspection systems which are specifically designed to support process control and optimisation. For example, the **argus** Universal Disc Measurement System is an off-line system which evaluates every physical and optical parameter necessary to support replication, for all disc formats. The **argus** is the only system which measures all properties in the replication process from the very first step (eccentricity) to the last step (lacquer thickness). By controlling disc temperature during the measurement the replicator can be confident that any changes that he makes to the process are based on valid measurement results."

Presentation of results and data handling is also carefully designed to assist process control. "By selecting the topographic view, the operator can instantly see the measurement results mapped across the whole disc surface," says Schwab. "It is therefore very easy to identify process phenomena which are characterised by particular symmetry distributions.

"The **argus** is network compatible, and results can be exported to applications such as Microsoft Excel for statistical analysis and comparison with results from other equipment such as moulding machines."

To complement the **argus**, dr.schwab GmbH also supplies inspection systems for fine-tuning mastering and stamper production, plus a comprehensive range of scanners for in-line process monitoring and control.

Schwab concludes: "Even for established formats such as CD-Audio and CD-ROM, testing has a part to play. Process control and optimisation through improved quality increases profitability and generates first-class product: good news for the replicator and his customers."

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