Deliverable 10.2

ML² – Multi Layer Micro Lab

Report on complete functionality of ML² production line

3. Lamination module

The controlling of register marks in lamination processes is different to the registration during printing processes.

In roll-to-roll printing processes, the detection of register marks takes place directly after the printing unit. The control loop is short and shows less parameters, whereas in the lamination process we have to control the substrate and the laminate and both its registration marks and its accuracy which leads finally to a more complex process.

As an exemplification, the printing process is influenced by disturbance which comes from one substrate. The role-to-roll lamination is influenced by the distortion of two substrates.

During a roll-to-roll Lamination process, we found the influences of other process parameters, which shows an unexpected disturbance value:

- 2 x influences by direction stability of the films “curving”. (2x PET or PMMA)
- 2 x Influences by printing process for registration marks “dust by LASER / screen resolution” (Registration mark quality)
- 2 x Influences by longer and different control loops (See Figure 2)

The focus for Coatema here is to identify the effects and to optimize the processability in form of optimized equipment and process controlling.

3.1.1. Direction stability of technical films (curving)

The production line is designed in modular units to optimize the complete lamination process with focus on short length and closed loop control path.

The basic film comes from unwinder and will be aligned by a pivot frame (edge guiding system).

After the pivot frame, the basic film passes as closed as possible – but realistic for industrial applications - way to the coating unit. Here occurs mostly movements of the basic film in cross direction (CD). These movements originate from the technical film. Slitted PET shows more or less curving in the film direction. (Fig. 1)

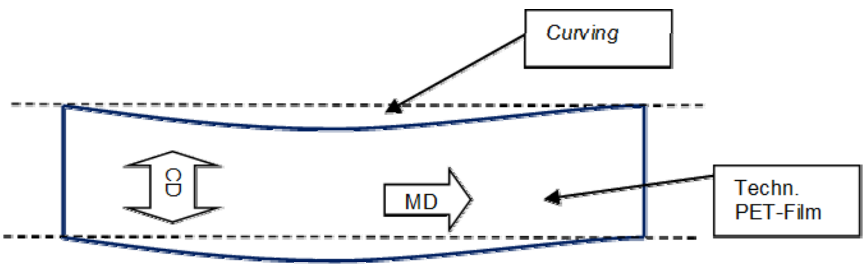

Fig. 1 Curving of technical films

These effect occurs before and after the guiding frame. In case of winding to rollers, the guiding frame should be installed closely to the winder to achieve a good winding accuracy. In case of lamination, there are long distances between the process steps. Mostly, after coating with wet and sticky adhesives, the basic film could not deflected by deflection rollers of a guiding frame.

3.1.2. Control loops

The distance between coating unit and lamination process should be very short (short controle loops). But in technical applications are additional units in the production line (hot air dryers / UV / IR).

Pre-Printed registration marks are effected only by curving between guiding frame and coating / printing unit. The printed marks flows the position inside the film with more or less constant offset to edge of film.

The lamination point is considerably more away from the last point of film guiding. The curving takes a big influence of the alignment of basic film.

And an additional curving effect comes from the films which becomes laminated.

Due to these effects, the investigation of the camera registration takes place initially without lamination.

3.1.3. Experimental setup

To test the accuracy of camera and detection process, the detection takes place without lamination. The test is carried out with different pattern of complete set of registration marks, to reduce the side effects of technical films during lamination.

These part of practical investigations has its focus on the detection of pre-printed substrates.

Test pattern:

1. Silk screen printed PET (Roll to Roll), Coatema
2. LASER pattern on PMMA, IPT Aachen

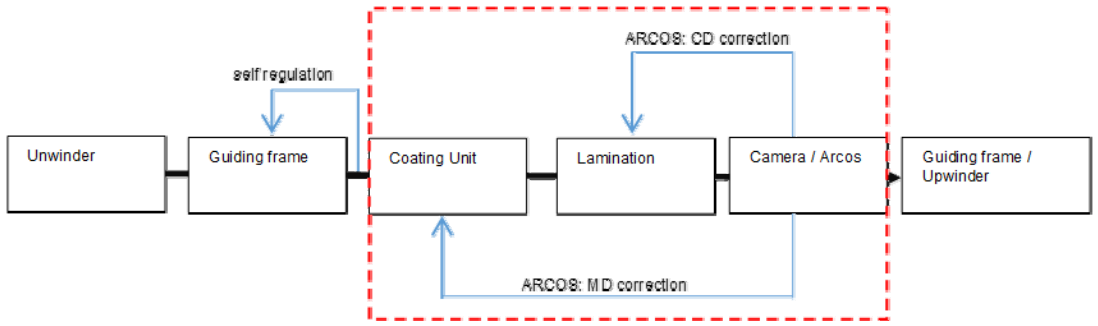

Fig 2: Control loops of registration and lamination CC08 / CC09

Fig: 2 shows the set up of the production plant. The control circle for lamination takes place inside the red collard frame.

The control loop for MD-correction (Arcos: MD correction) shows approx. the double length of substrate as in compare to the CD-correction (ARCOS: CD correction). Thereby, all correction input from software PID for MD needs the double of time to detect the corrective actions.

CD-correction: by moving unwinder of Lamination

MD-correction: by moderate the speed of coating unit

The response time between results of CD controlling and MD controlling is different. After MD control signal, the film ha to pass approx. 2m more than CD control signal inside the coating machine, before the detection by the camera system occurs.

Control path CD: approx. 180 cm

Control path MD: approx. 380 cm

Therefore in a typical process the accuracy for a lamination or a printing process should be reached after 2-10 m of substrate length. Configuration of the precise Lamination Module

Fig. 3 displays the configuration of the precise lamination Module inside the Click&Coat coating line, which has been designed and engineered in the ML^2-Project

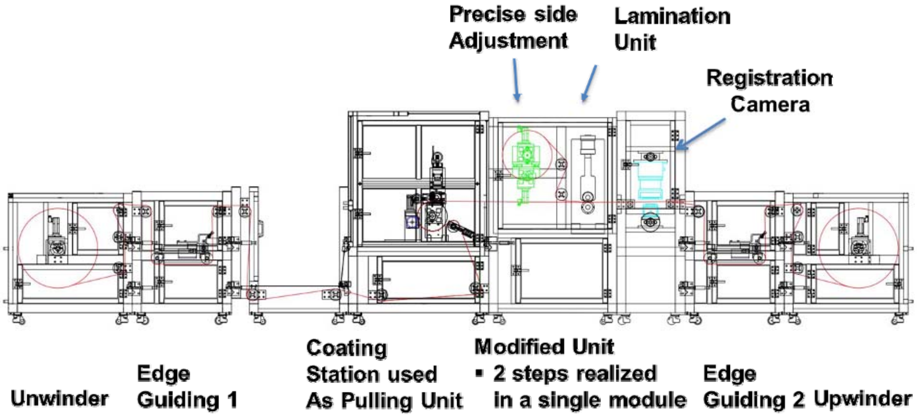

Fig. 3: Module configuration for precise Lamination

Due to the size of the Registration Camera Coatema has realized an individual module for the Camera (Fig. 3).

Fig. 4: Installed Registration Camera

During prime and basically tests, we see that - as a core requirement - the light situation inside the camera unit has to become stabilized. The Module for the registration Camera becomes equipped with light shields (Fig. 4 / Fig. 5).

Fig. 5: Shades of the registration Module to prevent errors caused by illumination and daylight

The encapsulation of camera system to reduce negative effects, caused by light incidence, stabilized the detection accuracy. It is a mandatory improvement.

3.2. Registration Camera System

3.2.1. Specifications for registration

Typical Specifications for the registration have been determined with the partners and with the OEM supplier of the Registration Camera. These Specifications are:

1. Detection of > +/- 5µm aberration of the Offcode specified register marks
2. Detection of register marks on: PET, PC, PMMA, copper, aluminum
3. Detection of register marks, made of opaque inks: black, red, white, silver, …
4. Detection of register marks, made of translucent inks: p-Dot-Inks, …
5. Adjustment speed: 0,4 mm/s
6. Adjustment range: +/- 5mm
7. Speed of substrate: 2 – 10 m/min

3.2.2. The test pattern

(Fig.5) According to the specification of registration unit, Coatema and ISP realized printing patterns (silk screen printing / LASER printing) to test different situations during a lamination process.

A: 1 dot for lamination, **B**: 3 dots for lamination, **C**: CD -1mm, **D**: CD +1mm, **E**: CD/MD 0,

F: MD – 1mm, **G**: MD +1mm, **H**: CD/MD 0mm

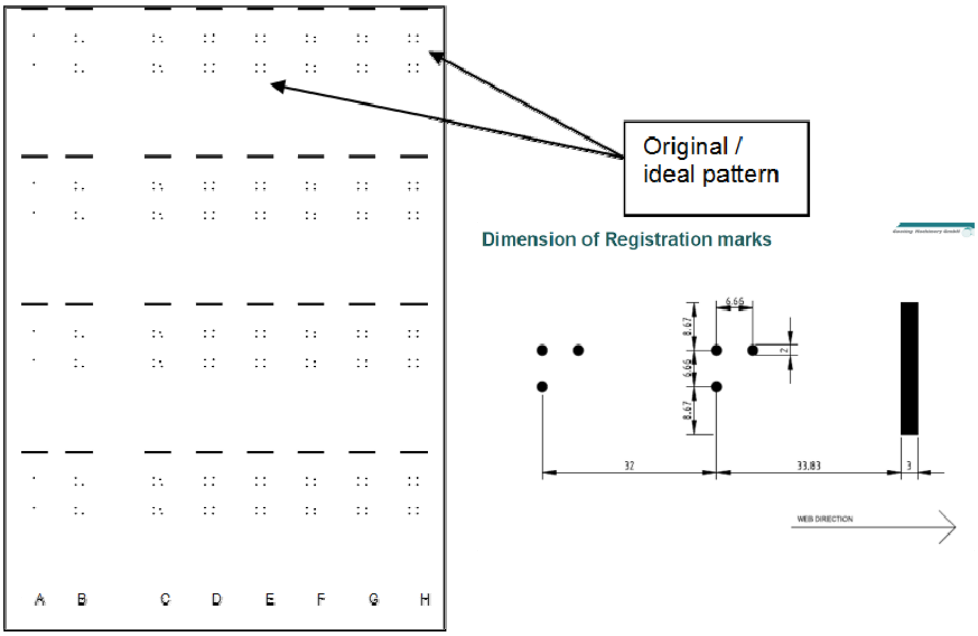

Fig. 6: Test pattern for roll-to-roll silk screen printing. Rapport 628 mm, 4 groups, Mesh SP250

3.2.3. Basic Tests with the Registration Camera / ARCOS Software

Figure 6 shows the LASER pattern from ISP during registration of the camera system. The test run is performed 5 x over the same sequence of registration pattern.

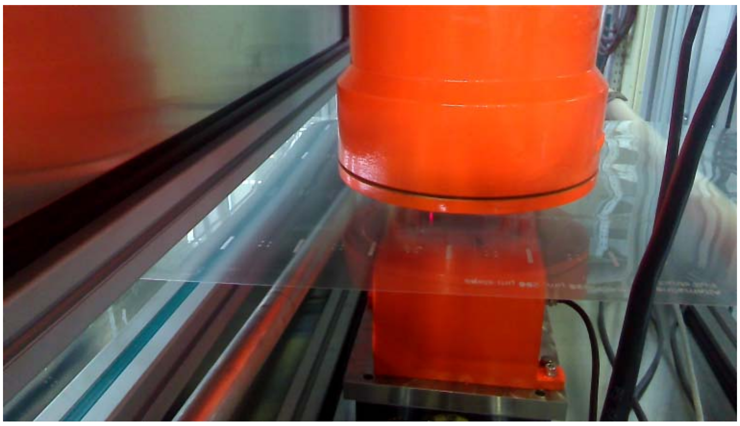

Fig. 7: Test material under camera system (sample FhI Aachen, Laser)

On each test run ARCOS produce a log file. These log files were aligned together based on the time stamp. Time stamps were some 3600 (9600 PET) ms apart and deviation of time stamps was below 20ms.

Aligned log files were presented as graph. Ones with predefined zero error presents the process error.

Some data was discarded at beginning and end of logs, so they align correctly. On PET samples rewinding caused change cross direction and this caused some missing data points in samples.

ARCOS measurement error was done numerically by calculating the deviation of the log file sample points.

3.2.4. Silk Screen printed PET

First we investigated the silk screen printed material.

Fig 8 and Fig. 9 presents the detected error of silk screen printed registration marks. Both direction should have zero error but in average the machine direction error (MD) is oscillating between 10 and -20 µm (Fig. 7).

The cross direction error (CD) was detected between 20 and - 15µm (Fig. 8)

Only the ideal pattern of the silk screen printing on PET was detected.

The other lines will be used to check the response between ARCOS Software controller and the final controlling elements of the lamination line (CD-correction unwinder lamination, speed correction of coating / printing roller)

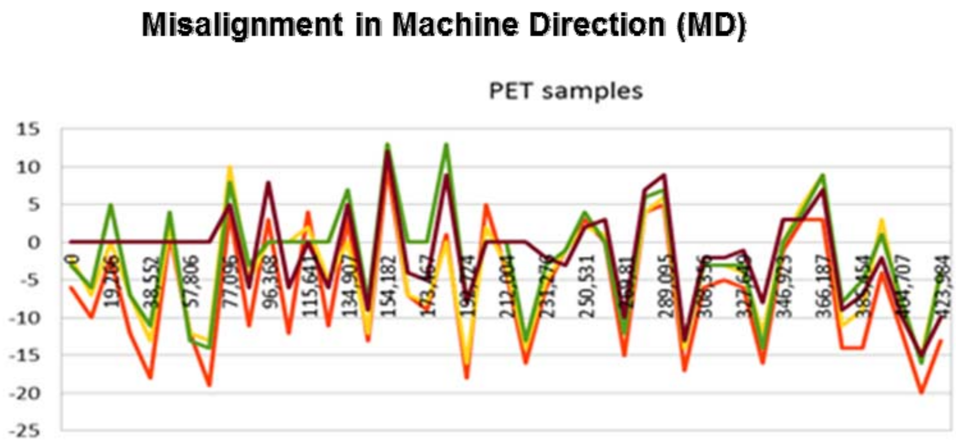

Fig. 8: Error detection MD, 5 x repetition for average determination, x-axes: time stamp of measuring / y-axes: divergence in µm

Performance in MD-direction: 10µm to -20µm

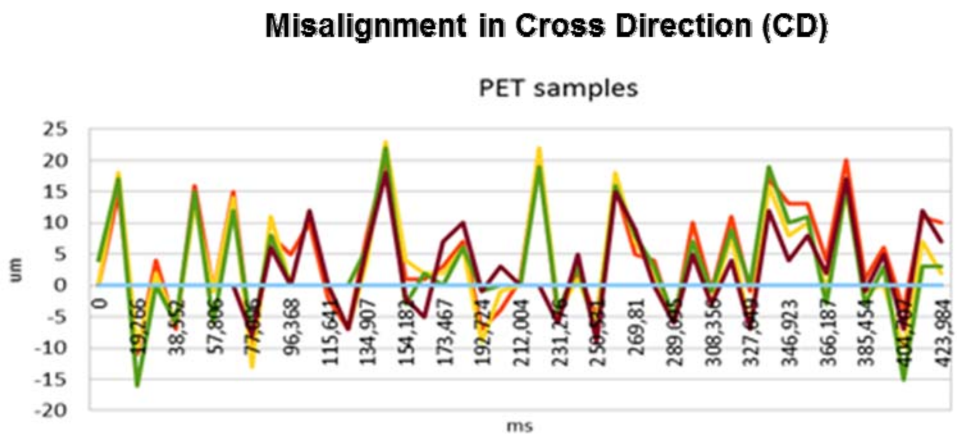

Fig. 9: Error detection CD, 5 x repetition for average determination, x-axes: time stamp of measuring / y-axes: divergence in µm

Performance in CD-direction: 20µm to -15µm

Average Performance: Fig. 8 and Fig. 9 prove that detection in CD and MD is working/qualified and demonstrates an accuracy of <+/-20 µm.

The Fig. 10 presents the measurement error. At cross direction there is one 6µm spike but in typically distribution of the detection error is below 5µm.

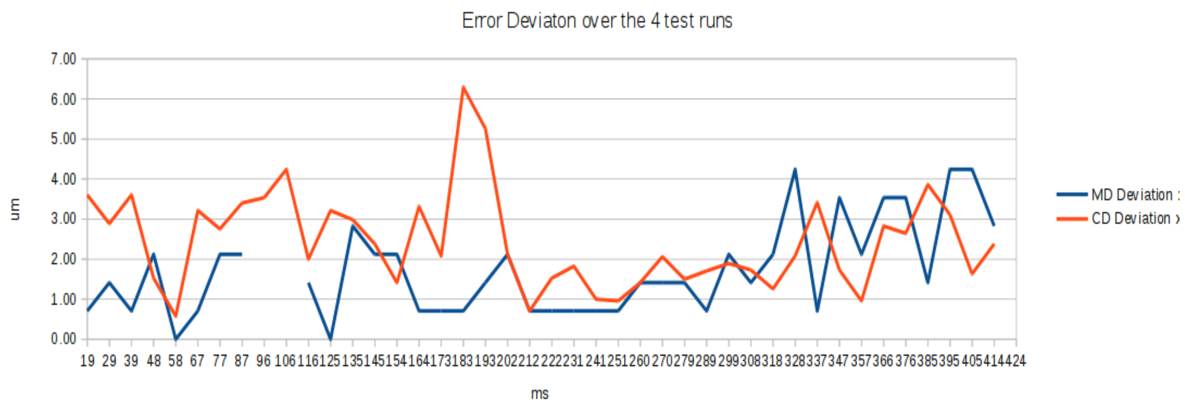

Fig. 9: PET error deviation between test runs (MD / CD), average of 4 x detection runs, x-axes: time stamp of measuring / y-axes: divergence in µm

This investigation demonstrated that the Registration Camera itself is able to detect the claimed specification of 5 µm in 3.1.

3.2.5. Laser engraved material (IPT Aachen)

Here we investigated registration marks provided by the IPT. These registration marks were engraved by a laser process.

The machine direction had zero error and cross direction has a premade 50 µm stepping error. These error is done on purpose and printed inside the marks. The basic film is made of PMMA

(thermos plastic)

Fig. 11: The worst results (blue box) are at first third, where the detected error variates from -200um to +150um. The best third the results stays in +/- 10um range (red box). The assumption for bad results is the dust that laser has produced around the mark. The results seem to get better after each run – so the dust is disappearing.

Additional test should be done by cleaning few samples and re-test them.

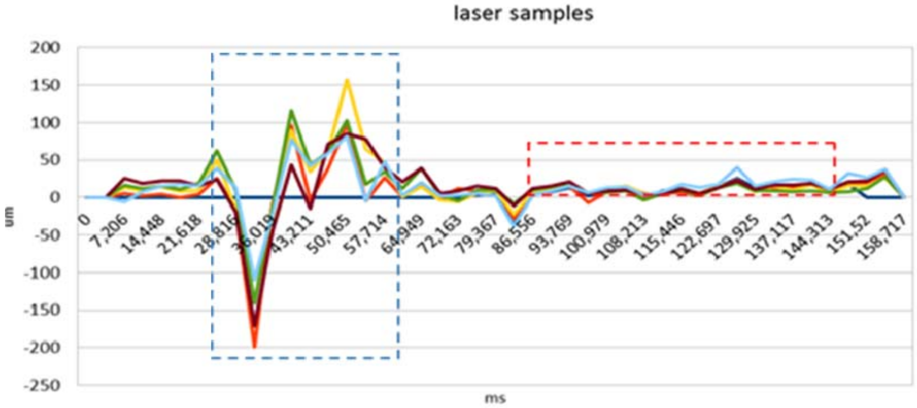

Fig. 10: Lasered samples – Machine direction (MD) zero, 5 x detection runs

Average error on this laser process seem to be somewhere below 10µm (linear average).

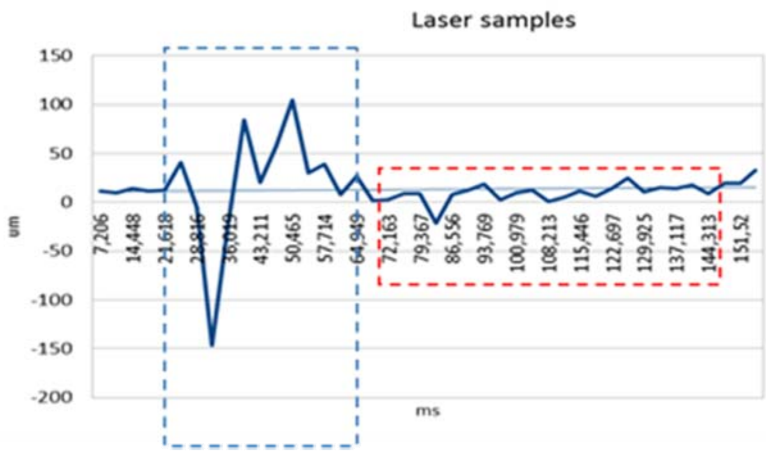

Fig. 11: Lasered samples -- Machine direction (MD) zero error, 5 x detection runs

In order to obtain a high information density with less variation, the test patterns were 5 x measured by the camera system.

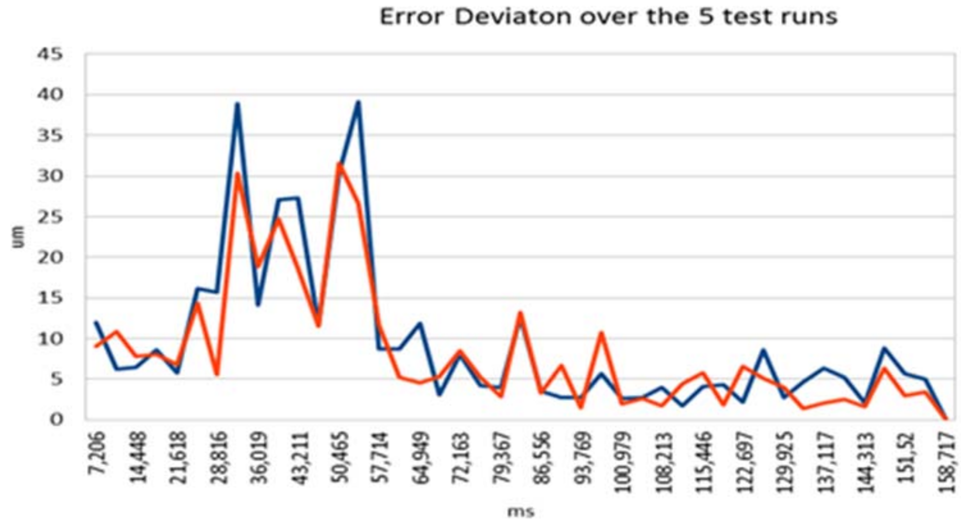

Fig. 12: Lasered samples – Detection error (MD and CD), average of 5 x detection runs, x-axes: time stamp of measuring / y axes: divergence in µm

The ARCOS measurement detection error was calculating the deviation of each measurement point in above samples. Again at first third of the sample has detection error variating up to 40µm. The disappearing of the dust in laser marks would explain this behavior.

Performance: At best third the detection error variates clearly below 10µm (below +/-5um).

Interestingly this is very near the measured laser process error – Thus it can be assumed that the errors are same and laser process is more accurate than the measurement.

During the detection of the laser marks, we found values of big errors. These errors do not fits to the majority of error values.

We found out, that the Laser printing process makes particles of evaporated thermoplastic PMMA. This particles looks like dust around the registration marks.

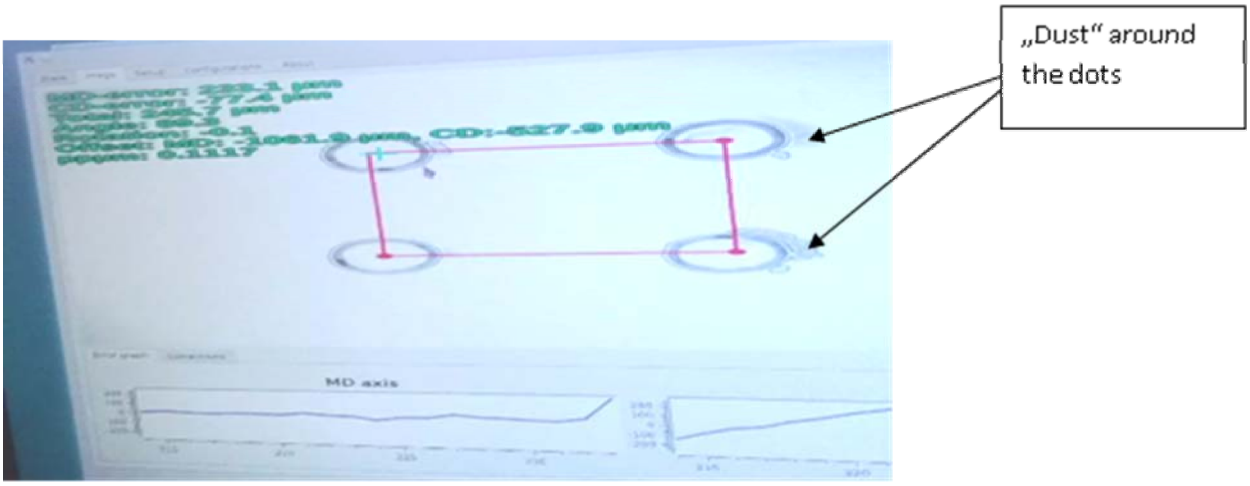

Fig. 13: Dust in the laser image

Fig: 13 presents the dust of the image. At final process it is essential that the extra dust is removed from the material. The dust comes from the high temperature evaporating LASER graving.

3.3. Summary of detection (pre-printed material)

Based on the tests following results will be expected on process.

Laser process error in MD	Below means accuracy (*+/-20µm
Laser process error in CD	Below means accuracy (*+/-20 µm
ARCOS Measurement error in MD	+/- 10um (*
ARCOS Measurement error in CD	+/- 10um(*
Silkscreen process error in MD	-10 to +20 um
Silkscreen process error in CD	-15 to +10 um
ARCOS Measurement error in MD	+/- 5um
ARCOS Measurement error in CD	Below +/- 10um

(* Processing the material with Laser generates dust. If this not removed the error may be more than 200 µm

The over-all error for the process is a sum of following terms:

1. Process – printing method, materials and machine accuracy
2. Measurement error – the detection error
3. Control error – the error caused by the Feed Back this is not measured on this test.

Base on Fig. 11, the Laser process can produce results in accuracy **below +/-10um**. However it is important that the dust is removed from substrate. Based on Fig. 7/8, the silkscreen printing on PET will produce results in accuracy somewhere **+/- 20 um**.

These test were done in laboratory without any optimizations of the printing process.

Further optimization such as cleaning 'dust' from laser marks and fine tuning silkscreen parameters will improve the overall accuracy.

As said before, the feedback loop error was not analyzed. However the process Feed Back requires a predefined correction step. This step must be bigger than process accuracy (the 'noise' of the process). This leads us to two cases of the feedback error:

1. The Process error doubles – assuming the feedback does not introduce any bigger new error.
2. We stay in expected rages of the process error, but we need to detect and discard samples that are produced during the feedback operation.
3. The error range of camera system / ARCOS Software is bigger than the expected error range of lamination unit (better +/- 5µm). The Lamination process fits to the determined accuracy of registration unit.

3.4. First lamination run

3.4.1. Test parameters for Click & Coate coating unit

The lamination was carried out under the following parameters:

Film: PET-Film s: 75µm (Melinex 506, Dupont), W: 500mm, Pre-printed roll-to-roll silk screen printing.

Adhesive: Henkel Loctite Liofol LA2760 / La 5028, 25% solid

Speed of line: 1 m/min.

Tear force unwinder: 80 N

Tear force up winder: 110 N

Tear force lamination: 15 N

Lamination gap: 120 µm

Lamination pressure: 3,5 bar

Main parameters for Camera system:

All LEDs: on

Camera gain: 83

Resolver: 1418 / Cut off 10

3.4.2. Observation / monitoring of trials

During the start period, the detection and visualization of the software shows a error in MD of approx.. 800µm and in CD approx.. 700µm (Fig: 15). (The MD correction is not inside the visualization).

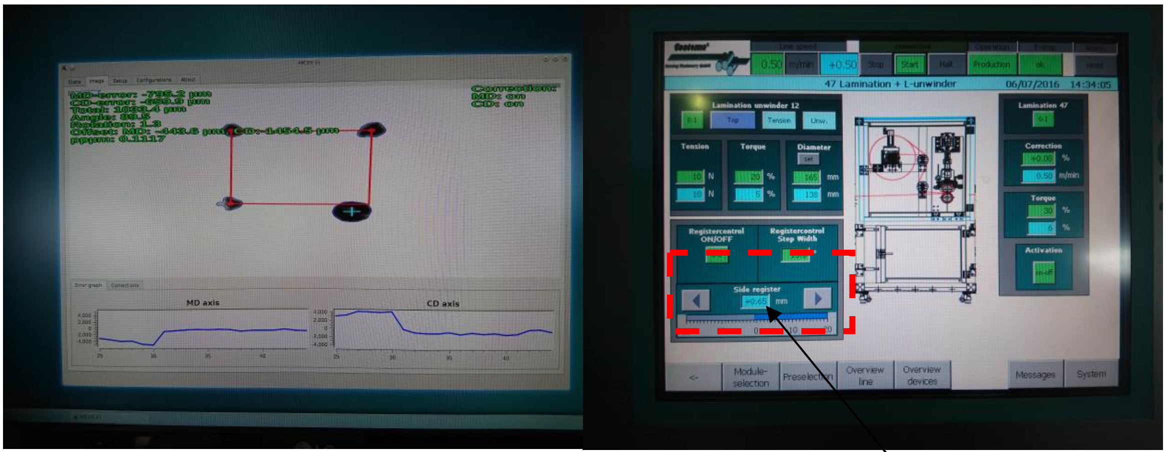

Fig. 14: left: ARCOS Software first detection and error calculation /

right: response in CD of CD-Driver

Oscillation of unwinder Lamnation (CD) "+0,65mm"

After 3 pictures and calculation runs of the ARCOS software, the software PID send first control signals to the driver of CD and MD direction (Fig 15.)

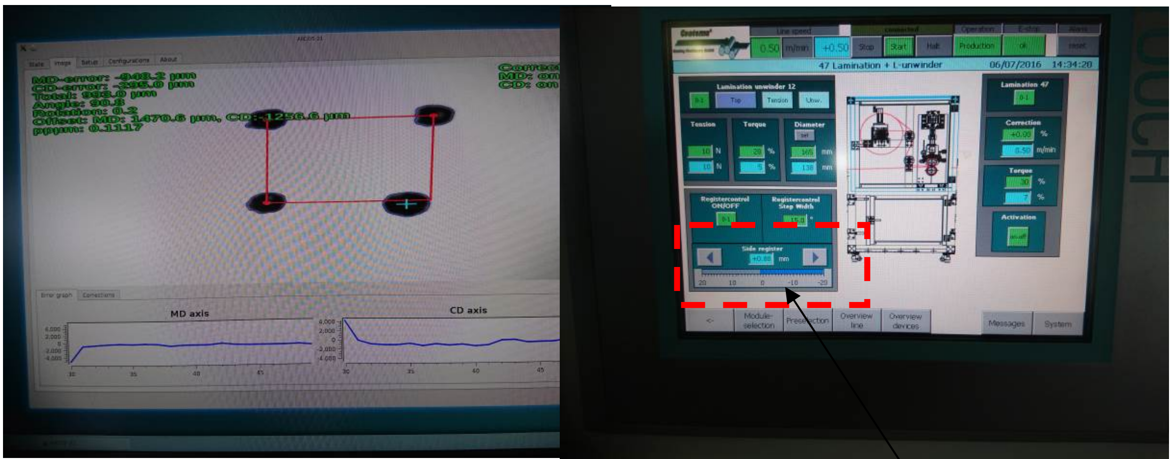

Fig.15: left: ARCOS Software after 3 detections

right: response in CD of CD-Driver

Oscillation of unwinder Lamnation (CD) "+0,88mm"

During the trial we have monitored 178 pictures and as the result 178 x MD/CD correction signals. After 21 circles of controlling, we achieved a short period of additional 28 circles of controlling with small controlling signals to CD and MD.

In a later production period, we found a better situation for MD (Fig. 16).

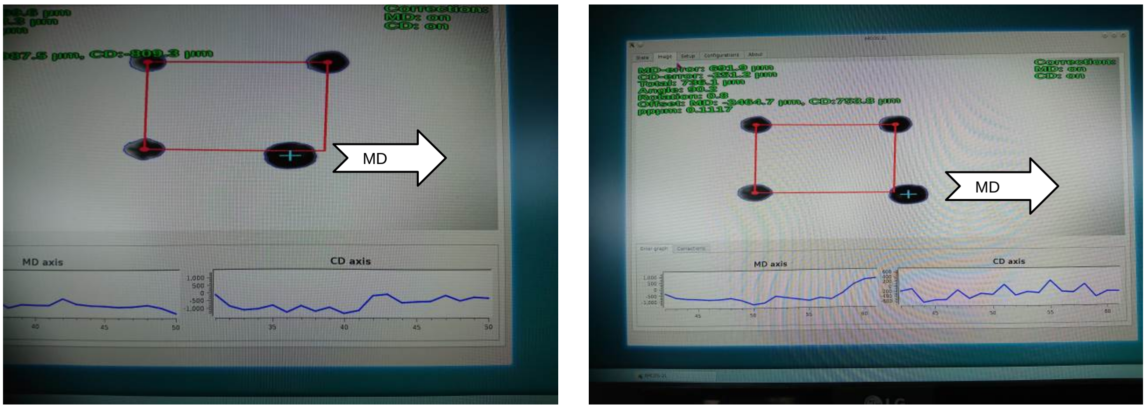

Fig: 16 controls signals for CD direction are stable. The controller for MD direction shows big error values

The response of CD and MD registration by the software PID (Arcos) becomes logged. The errors in CD / MD direction can be visualized in a time stamp diagram. (Fig. 17 ff). The time stamp is a period of time in [ms].

During the tracking of registration marks we found first a period of big differences. According to a typically PID- control loop, the results swing by to a second period, the “oscillation control mode”.

After a period of convergence to a minimum of differences, the control loop suffer a massive disturbance or get out of control by suboptimal parameters.

We observed the two technical films during the lamination. And we see that the **curving** of the films provoke a massive distortion in double effect in CD.

During the controlling of MD we observed a big influence of the distance between coating drum and registration camera. The basic film stretches over a long distance. The response to these actions is temporally delayed..

3.4.3. Results of lamination trial

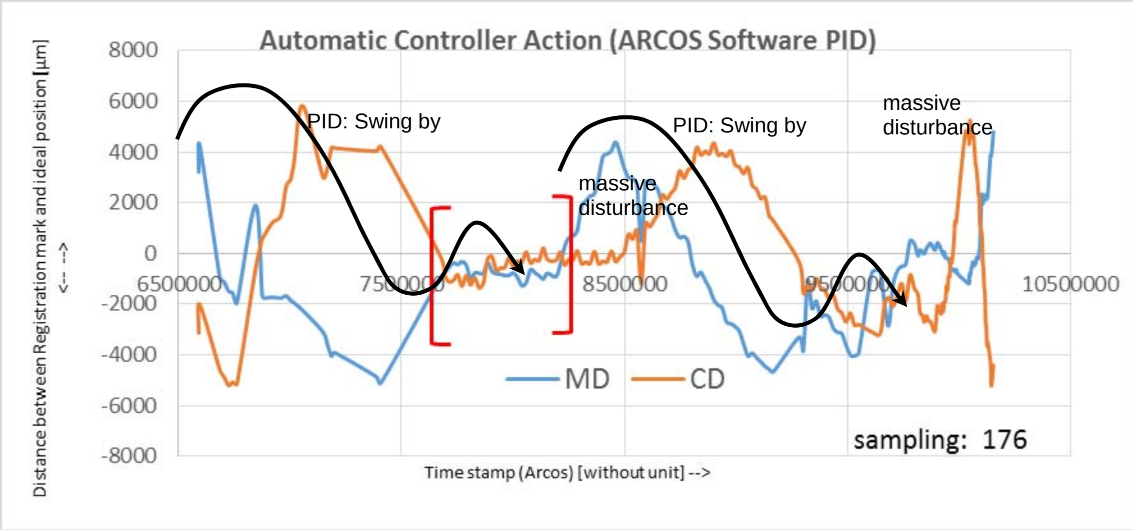

Fig. 17: After response to the automatic controller the movement of CD- and MD- registration

Fig. 17: During the start period, big differences (big errors) induce a big response value to the control element (→ PID signal to Driver for CD or MD correction). The damping part of PID leads to a more and more reduced error, but in nature of PID controller, its leads to an over and under swinging of error values around the index value (PID swing by)

In case of bad parameters and in case of massive unexpected or not filtered values of disturbance, the automatic controller action could become unstable.

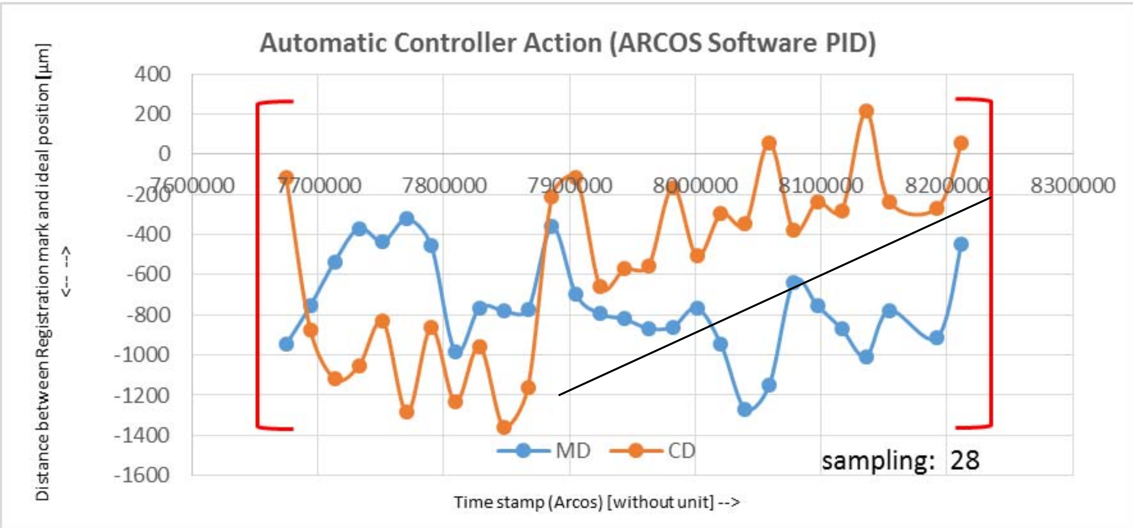

Fig. 18: Details out of the data of 178 measurements

Fig. 17 and Fig. 18 shows the trending during the PID-regulation. The errors in CD- and MD-direction getting smaller and smaller.

In the first trials (not optimized) we have achieved:

Error CD: approx. +/- 200 µm Error MD: approx. – 250 until – 1200 µm

We are optimistic that we can achieve a significant improvement here. The parameters of the PID controller must be adapted.

3.5. Coating and Lamination line CC09 at FhI IPT

The Click&Coate unit CC09 of the project partner Fraunhofer Institut IPT, is directly comparable to Coatema CC08. Between Coating System and Lamination system are matchable distances. The control loop is similar on both machines. Important machine parameters are comparable, too.

Coating speed range:	0,2 to 10,0 m/min.
Coating width:	500 mm
Tensile strange:	50 to 500 Nm/width
Diameter of deflection rollers:	120m / Imprint: 200 mm
Lamination gap:	adjustable
Lamination pressure:	up to 6 bar

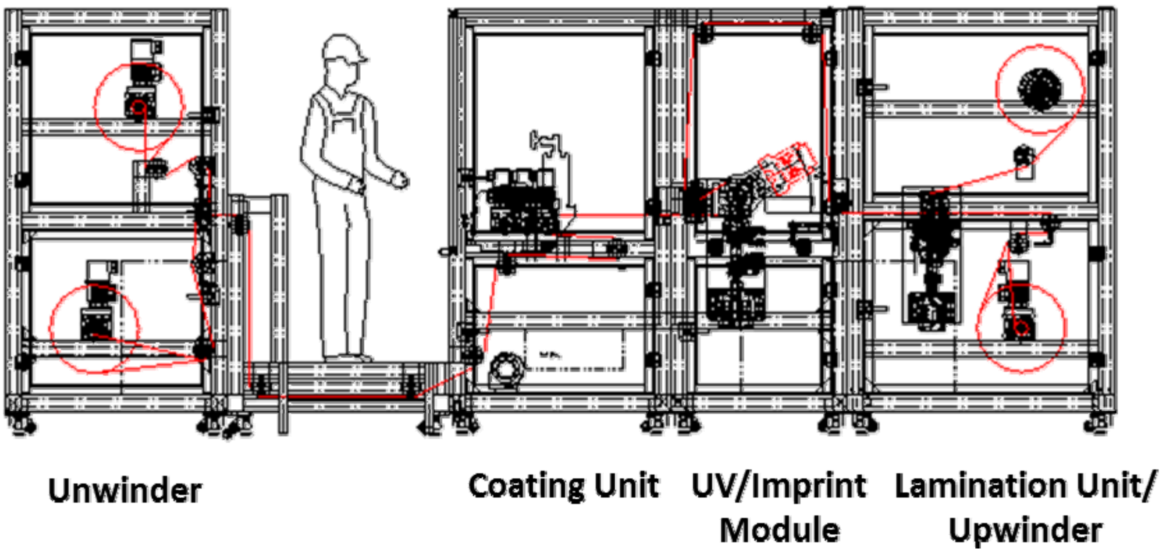

Fig. 19: Click&Coat Coating and Lamination Unit CC09

Important for the controlling of MD-direction will be the coating unit and / or the imprint module. In CC09 takes place a 3 roller coating unit and a slot die system with coating roller, driven by one driver.

The imprint module is driven by one driver too. In case of imprinting and inline lamination, the driver of the imprint module could be used to manipulate the MD direction of registration marks (printing, not lamination).

The 3 roller system consist 3 drivers and have to be controlled in case of registration controlled lamination processes.

But this is not in focus. The implementation and investigation of MD/CD-registration controlling on / CC09 system is focused on slot die coating / imprint and controlled lamination.

The task is: Lamination of 2 or more layers, offline equipped with registration marks, controlled by registration system (camera).

The slot die system and the lamination unit of CC09 matches to CC08 at Coatema. By this, the investigations of slot die / lamination process are transferable.

3.6. Discussion of results

So far we have achieved following results:

1.) The camera system and registration software Arcos can detect the registration marks in range of spec of +- 5 to 10µm. To achieve these good results, the marks have to be printed in a high quality process (LASER).

2.) The basic results between screen printing and LASER-labeling show differences clearly. The repeatability of the measurements shows the stability of the novel lamination module and its process stability and the integrated camera unit.

3.) To improve the detection results of screen printing, the screen and the printing module should be more verified:

   1. Screen with a high resolution mesh, to achieve more round and crispy edges of the registration marks (mesh during first trials SP265, improved mesh SP315 /350)
   2. Better intermodulation factor during screen manufacturing. The dots become a better shape of a circle.

4) The conclusion of the lamination run is, that the PID-parameters have to become more optimized.

We expect, that the main parameter is influenced by the physical characteristic of the film, like:

- Coefficient of elasticity of the substrate
    - Influence by thickness
    - Influence by web tension

Caused by these, we expect an individually set of parameters for different substrates.

During the swing by of the PID-controller, we find trends to get much better results for CD and MD.

The massive disturbance after a period of convergence can be improved by PID-parameters.

With all discussed measures to improve the registration accuracy we are confident to reach typical values of CD ~ 30µm and MD ~ 50µm.

4. Printing module

4.1. Introduction

Thanks to its versatility inkjet printing has gained a lot of interest as a cost efficient replacement for established analogous printing and production techniques in different industries. Moreover in the last two decades it has been shown that it is possible to develop functional inkjet processable fluids which after film formation and post treatment lead to the needed functionalities for a lot of different applications, for example numerous sub processes in the microelectronics industry. However the conversion from conventional analogous techniques towards inkjet and especially the industrial implementation very often is challenging due to the complexity of inkjet technology. The basic concept of droplet generation is given by the natural instability of a liquid jet which is a complex surface tension driven process. In high throughput industrial single pass printing systems millions of microscale droplets are generated every second. The precise control of droplet generation and the overall process for accurate placement of each droplet on the substrate is of major importance. The mentioned overall process can be represented by the so called magic triangle of inkjet which is shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**.

Within the ML^2 project and the underlying idea of roll to roll production of multilayer microlabs different sub processes where inkjet printing could be an efficient production technique can be identified. These sub processes are:

4.2. Single pass inkjet printing system – mechanics and implementation

As described in chapter 4 the magic triangle of inkjet printing is defined by three main components. One of these are the printheads and the process which led to the decision which industrial piezo drop on demand printhead fits best for the requirements of the ML^2 project is described in chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**. Nevertheless in a real industrial printing process more is needed than just precise adjustment of printing parameters on stationary printheads. Because of printhead maintenance and height adjustment due to variable thickness of the substrates the printheads have to be moved in two dimensions. Another main component of the magic triangle is the media and media handling system. The movement of the substrate underneath the printheads is done by a vacuum conveyor belt system which is able to handle flexible and rigid media. Figure 4 and Figure 5 show a CAD drawing and a photographic image of the ML^2 single pass inkjet printing system.

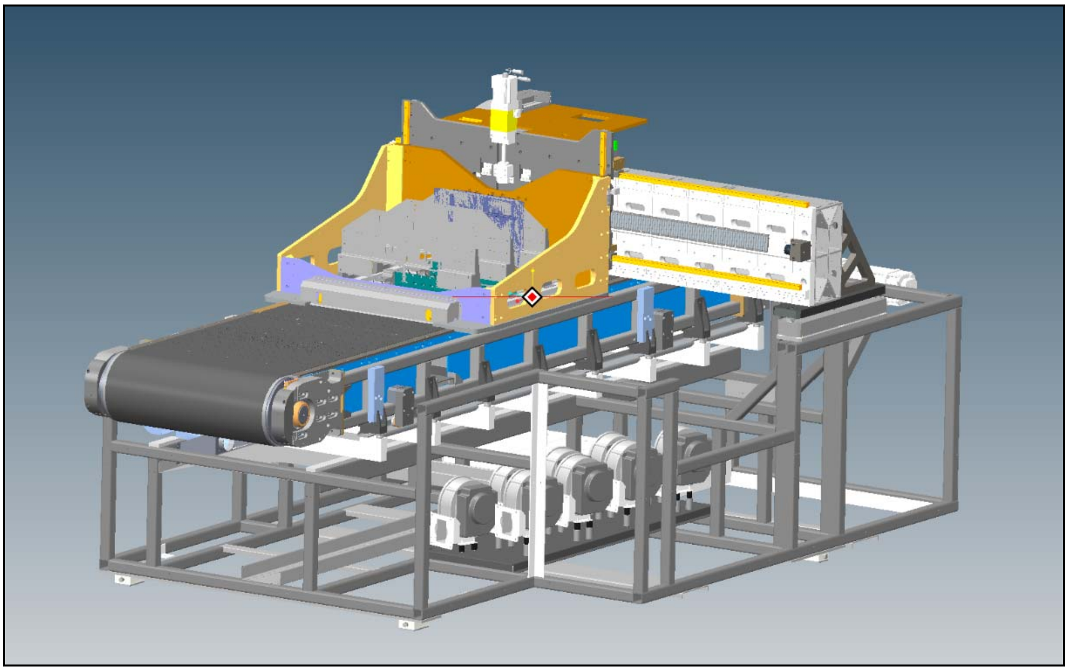

Figure 4: CAD Image of the ML^2 single pass inkjet printing system without casing, printheads and ink management system

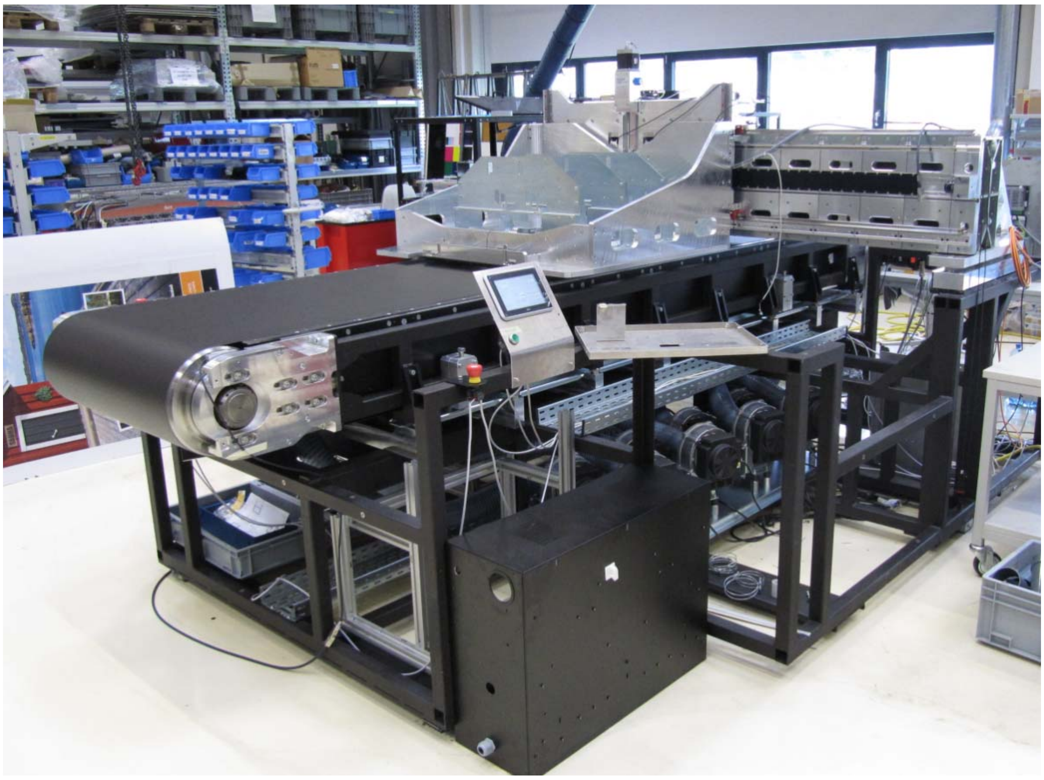

Figure 5: Photographic image of the single pass inkjet printing system

The printheads will be mounted on a carriage which can be moved in two dimensions. Figure 6 and Figure 7 show a CAD drawing of the carriage and the support which holds the carriage and a photographic image thereof respectively.

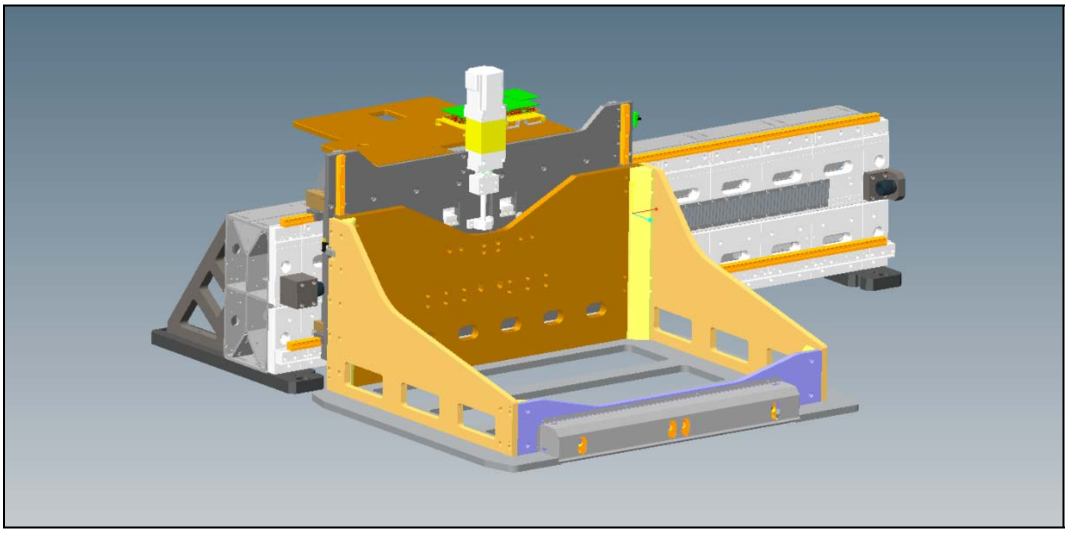

Figure 6: CAD drawing of the carriage and the support which holds the carriage

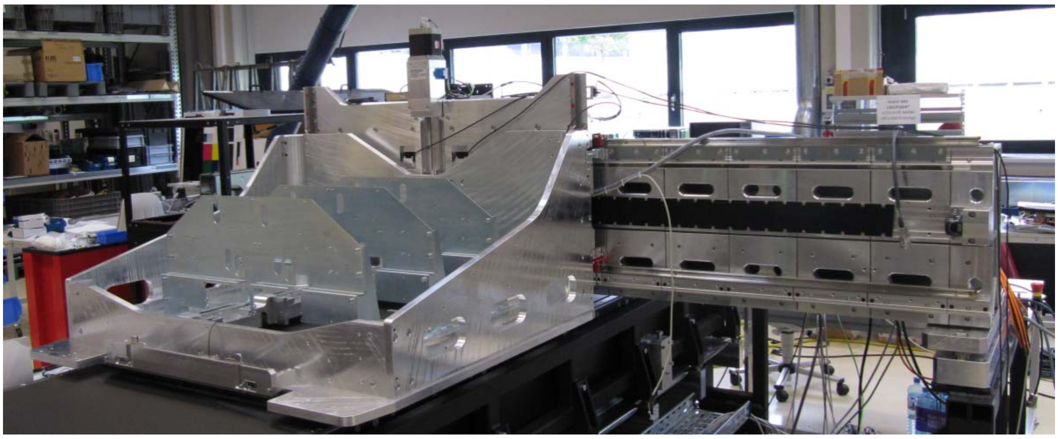

Figure 7: Photographic image of the carriage and the support

The z – movement of the carriage is done by a stepper motor with integrated encoder with a maximum travelling distance of 180mm. The support contains a rail system which allows the x – movement of the carriage for maintenance. In that direction it is driven by a linear motor which allows precise adjustment of the position. All axes including the vacuum conveyor belt are controlled by a Beckhoff automation system and accessible via touch panel.

One of the main components of the single pass inkjet printer is the media handling system. As already mentioned the single pass inkjet printing system has to be able to handle rigid and flexible media. Therefore a high precision vacuum conveyor belt system was designed which fulfils the requirements of the ML^2 project. Due to the fact that the media handling system has a big impact on possible printing accuracy it has to be very well engineered and strategies to optimise velocity uniformity and minimise drift of the belt have to be developed.

Figure 8 shows a CAD drawing (left) and a photographic image of the conveyor belt system.

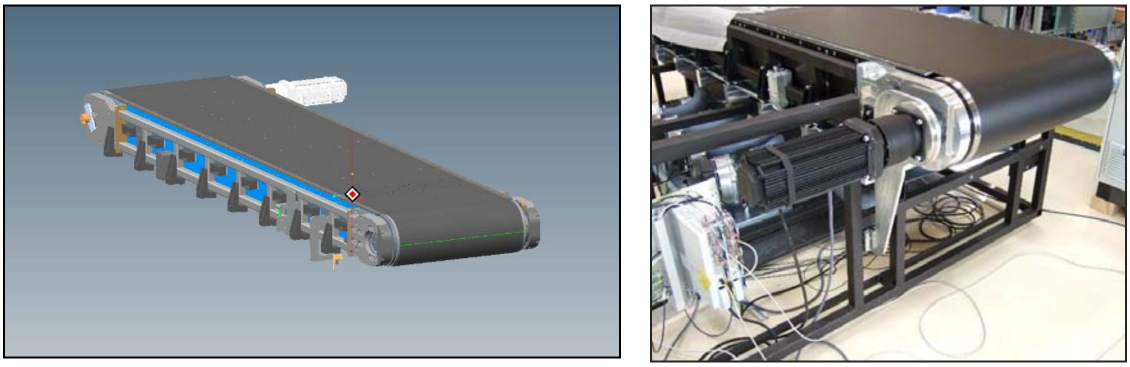

Figure 8: CAD drawing (left) and photographic image of the conveyor belt system

The belt of the current system is made of a polyester mesh with polyurethane topcoat and has a width of 800mm. The overall system is designed in a way that also a stainless steel belt could be used. A slightly decreased pressure in a vacuum chamber underneath the belt, which has punched holes with a diameter of 2mm, fixes the substrate at the required position. Figure 9 shows a CAD drawing of the belt with punched suction holes.

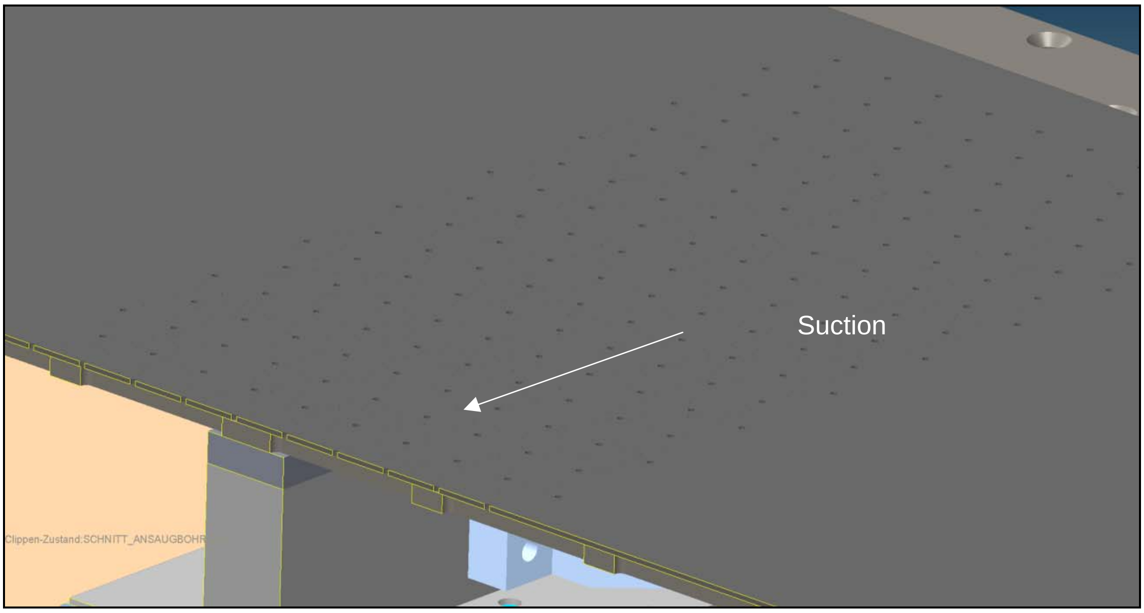

Figure 9: CAD drawing of the belt with suction holes

Extensive tests with 50µm PMMA sheets were performed to ensure that the distortion of the thin substrates through the cross sectional area of the punched holes does not have a negative influence on the printed image. These tests clearly showed that this is not the case.

The conveyor belt system is driven by a servo asynchronous motor (nominal torque 6,7Nm) with coupled planetary gear which allows a maximum linear belt speed of 60m/min. Measurements of velocity uniformity clearly showed that at a linear speed of 1m/s the maximum variation is 1mm/s.

For precise control of the belt position on the rollers and for preventing a belt movement in cross process direction an active belt control system is implemented. It consists of a tensioning roller which forces a tension gradient to the belt and this leads to a controlled movement in cross process direction. The actual position of the belt on the rollers is measured by a laser micrometer which is triggered by a light barrier to be able to always measure at the same position. It can be shown that the maximum belt movement in cross process direction is less than 100µm over one passage (which corresponds to 8,5m) at a speed of 60m/min.

3.1 Ink Supply and drying system

The choice of a suitable ink supply and recirculation system is essential for a stable operation of the printer. The main requirements in the current machine were a high enough flow rate to drive 8 Samba printheads per colour, compatibility with the used inks as well as a minimized volume in order to keep the amount of fluid needed to fill the system as low as possible due to the high pricing of most functional inks.

The optimum flow rate for a Samba head is approximately 35ml/min, thus meaning that the recirculation system must provide at least a flow rate of 280ml/min. Since material compatibility must be achieved with various fluids, very robust gasket materials should be implemented. These requirements were fulfilled by the CIMS2 ink supply system from the British company Megnajet (Figure 10), which can reach flow rates up to 400ml/min. After compatibility testing standard FKM gaskets were replaced by highly inert FFKM as well as EPDM. The tank volume of the system is only 50ml, which allows to drive the whole ink supply with an ink volume of approximately 300ml.

The flow rate of the ink supply is set by the differential pressure between infeed and return lines, while the meniscus pressure at the nozzleplate is adjusted by changing the return pressure relative to ambient conditions.

In order to avoid bubble formation during printing as well as printhead contamination, additional filtration and degassing devices were installed between the main unit and the printheads (Figure 10). For efficient degassing, a vacuum with a pressure of -900mbar relative to ambient was applied to the modules.

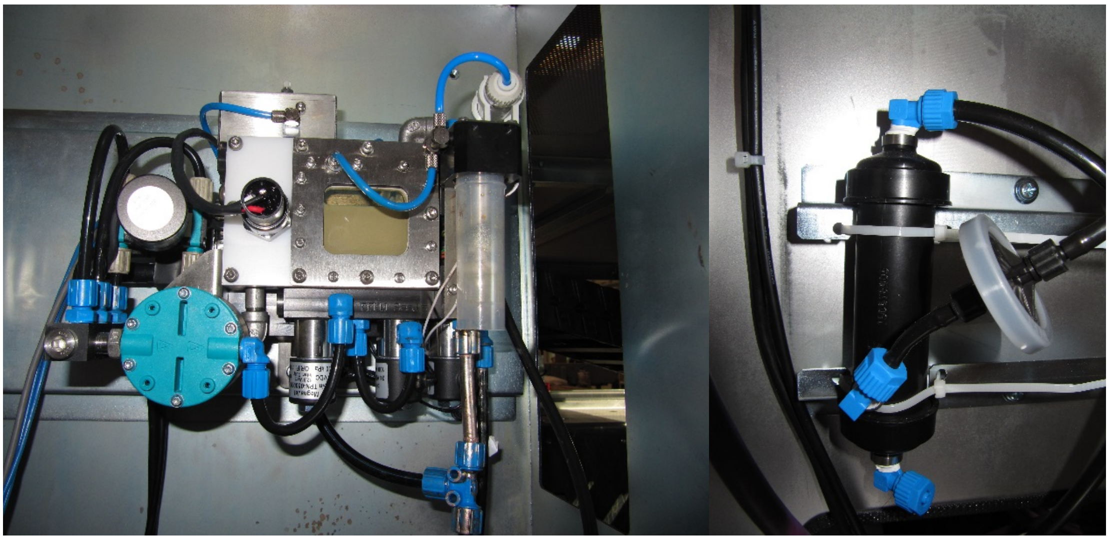

Figure 10: Left: Main unit of the ink supply system. Right: Inline filter and degassing unit.

During testing it turned out that the system was not running stable enough due to the quite long tubing between the ink tanks and printheads. In order to resolve this issue, Megnajet provided additional sensor units to be mounted on the printhead carriage (Figure 11), thus reducing the distance between pressure sensors and printheads from 5m to less than 1m.

From these remote units the tubing leads to 2 manifolds where 4 printheads each could be attached (Figure 11). In order to maintain ink circulation even in the case no printhead is attached or the heads being clogged, a small bypass is included in the manifolds.

Before filling the actual ink, each ink supply was flushed with the respective carrier vehicle in order to clean the systems from residual manufacturing contaminations as well as to provide better wetting.

Figure 11: Left: Remote sensor unit. Right: Head attachments and ink delivery ports.

Before printing tests could be performed, the inks were evaluated on a drop visualisation system (**Fehler! Verweisquelle konnte nicht gefunden werden.**), which included the creation and tuning of suitable electrical pulse shapes (waveforms) to optimize drop formation, volume and velocity as well as stability tests. After loading the ink in the printer, nozzle testpattern (Figure 12) were printed in order to adjust the printhead positions relative to each other and check for missing nozzles.

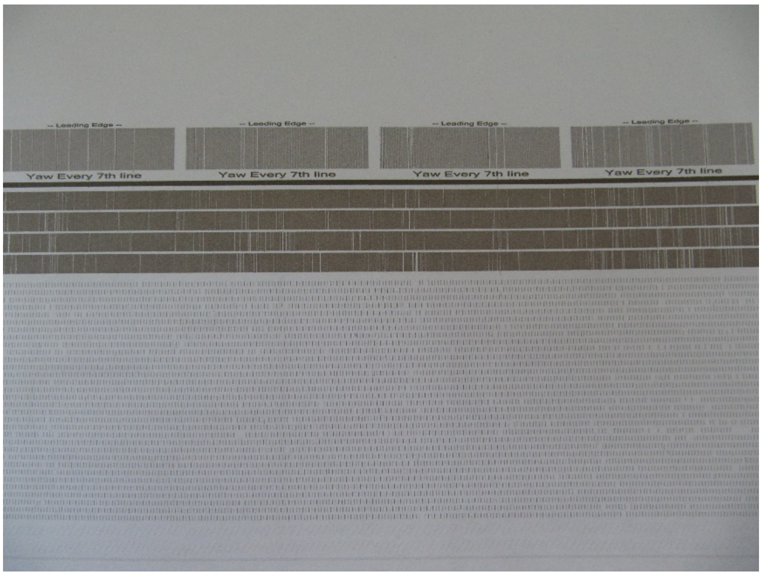

Figure 12: Nozzle testpattern.

Here one of the biggest advantages of the Samba printhead comes into effect: the high native resolution of 1200dpi. Even if individual nozzles are missing, the visual appearance as well as the conductivity of printed images are not affected (Figure 13), as long as the gap created by a missing jet is covered by the neighbouring nozzles, which is the case on most substrates.

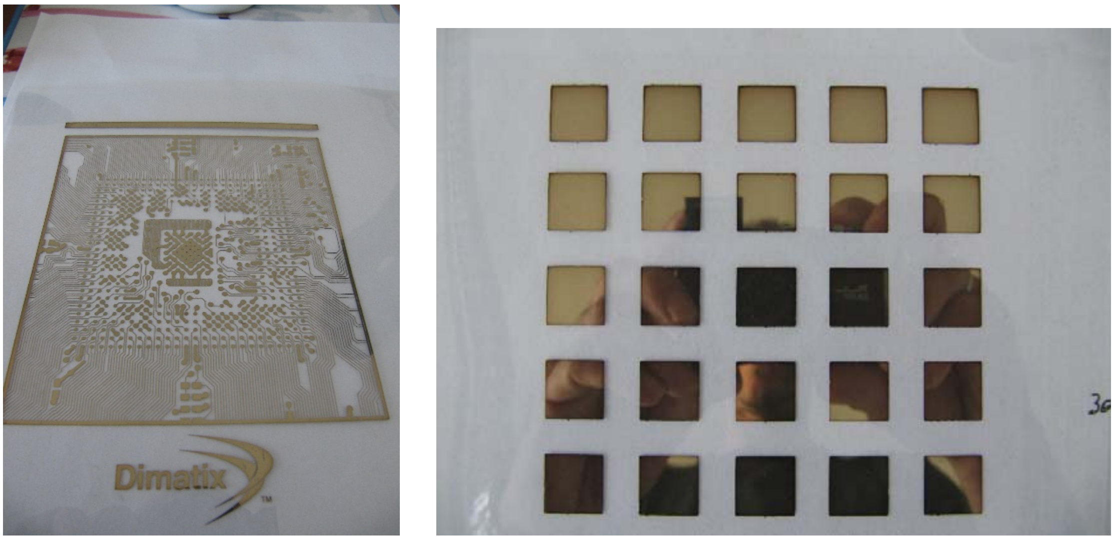

Figure 13: Test images printed with silver ink.

In order to increase the conductivity of printed structures, either the resolution or the size of the drops has to be increased to achieve higher layer thickness. While the first is difficult to achieve due to the nozzle arrangement of the printhead, the drop size can easily be adjusted by changing the voltage of the applied pulse or by using multipulsing, which utilizes the resonances in the printhead to generate one large drop out of several pulses. An example for such a waveform, which allows the creation of drops between 3 and 9pl, is shown in Figure 14. Thus the jetting performance can be adjusted to various applications, inks and substrates.

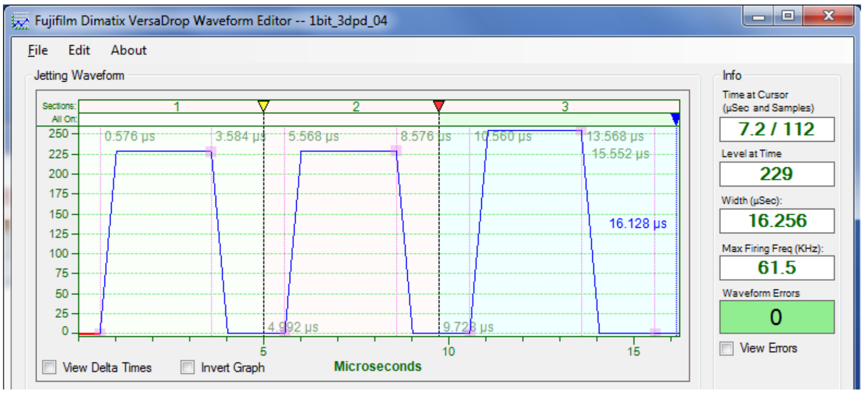

Figure 14: Multipulse waveform for the creation of larger drops.

Since a Novacentrix Pulse Forge Device will be implemented in the pilot line, full sintering of conductive inks is not required within the inkjet printer, but only a pre-drying step to fix the ink drops on the substrate (pinning) had to be implemented. Near Infrared (NIR) turned out to be the most suitable solution, since the emission spectrum is shifted towards shorter wavelengths compared to standard infrared systems, thus causing less absorption by thin film substrates and subsequently less substrate deformation.

The used system from Adphos is located on the conveyor belt after the printing carriage and has a width of 550mm (**Fehler! Verweisquelle konnte nicht gefunden werden.**). Thus the less homogeneous areas at the edge of the emitters are not used and more uniform drying can be achieved. The dryer is equipped with 3 emitters of 5kW electrical power each, yielding a maximum power of 15kW or approximately 22W/m². In order to avoid overheating of the conveyor belt at low printing velocities, only 2 of 3 emitters were used in most tests, which is sufficient for pre-drying in many cases.

In order to get rid of evaporated solvents, the drying module is equipped with an exhaust system. In case the conveyor belt stops, the NIR module switches off automatically to avoid substrate or belt overheating.