Contents

This document is a broad introduction to Hammer-IMS, its millimeter waves, and how they can be applied for automation in the plastics converting industry.

Quality and efficiency

A production process' quality and efficiency is of utmost concern to Hammer-IMS. The state of quality and production efficiency has an important impact on the profitability of a manufacturing company. Increasing product quality enables companies to provide solutions for new and highly-demanding customers, at a much more competitive position to their closest competitors, or even give companies the ability to increase sales prices in their respective markets. Whereas increased quality acts as an enabler for more revenues, increased efficiency, on the other hand, cuts production losses or operational expenses. Both increased quality and efficiency add up to more profitable manufacturing. Hammer-IMS's solutions focus on both quality and efficiency in the heart of the manufacturing process by contributing with innovative measurement technology to industrial automation.

Industrial automation at a glance

Ever since the start of the industrial production, humans wanted to put some level of quality on the products that they made, moreover at the highest-possible production efficiency. During the early days of papyrus manufacturing by ancient Egyptians back in 3000 BC, the level of quality has been guaranteed by a skilled human eye. The human eye served as a 'sensor'. Although this human eye is still believed to be the best sensor for production of small batch sizes, the human eye is expensive, subjective, sensitive to human failure or misinterpretation.

The first and generally-accepted case of automated production by 'non-human sensing' has been invented by Edmund Lee and patented in 1745. Edmund Lee proposed an interesting solution to the area of wind mill technology. The patent described the presence of a fan tail, acting as a sensor, on a wind mill. The fan tail enables the mill to find the direction of the wind in a fully-automated manner, increasing production efficiency. Edmund Lee couldn't have foreseen in 1745 that this innovation is to be believed being the first case of production automation.

Let's zoom on the concept of automation. Automation is the concept behind industrial processes acting by means of several control loops. These so-called control loops are some kind of way mechanical, electronical, optical, organic, … systems interact with each other. The general concept of a control loop is drawn below:

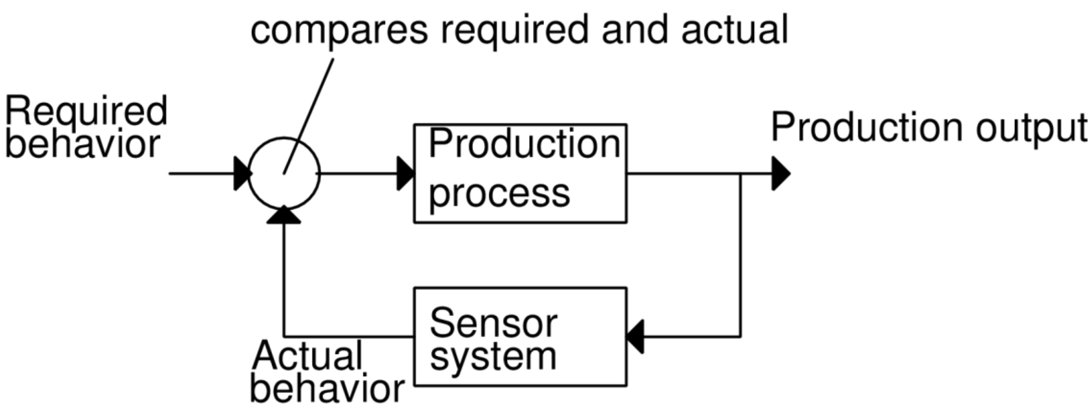


Figure 1: The general concept of a control loop

A control loop ensures that industrial processes keep working as desired. Important parts of this control loop are: the *production process*, the *sensor system* and the *controller* (the circle). The latter compares the required production process' behavior with the actual behavior of the production process, captured by a sensor and steers the production process as desired. Too complex? Let's take the wind mill case again. The 'block-diagram' of the wind mill case looks as follows:

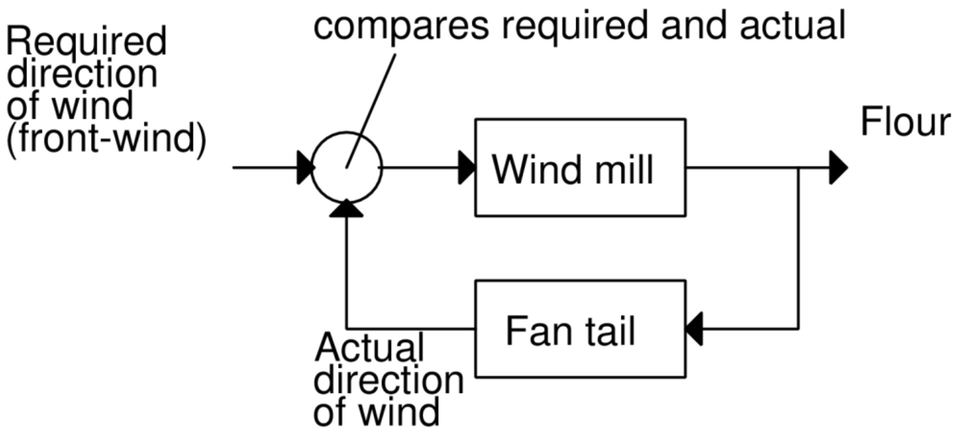


Figure 2: The concept of a control loop applied to the 'wind mill' case

The production process is in this case the wind mill, taking care of the production of flour. The sensor system is the fan tail, tracking the wind direction. The controller (the circle), a mechanical system, will compare the detected wind direction with the most-ideal one (front-wind), steering the wind mill in the proper direction.

Hammer-IMS in industrial automation

Hammer-IMS is not about the *production process*, neither about the *controller*, but about the *sensor system*. Hammer-IMS provides sensor systems for industrial control of both quality and efficiency. The terminology of 'sensor system' is often somewhat too general. Hammer-IMS provides quantitative information about production processes, and therefore the terminology of a 'measurement system' is much more preferred.

Much like the human eye and the wind mill's fan tail used to be key sensors in industrial automation, Hammer-IMS believes that millimeter waves are key in certain applications. To identify these applications, we will first introduce you to some important aspects of these millimeter waves.

Millimeter waves

When people hear about waves, they tend to draw a sinus line with alternating highs and lows. Millimeter waves are, to that extend, not different from other waves. Millimeter waves are the unique asset of Hammer-IMS. Unlike the waves of the sea and the acoustic waves that you produce while you speak, millimeter waves do not use a medium (water for the sea's waves, air for speech-waves). Millimeter waves are electromagnetic waves. They are comparable to the ones that are used in FM-radio, WiFi, GPS, cell phone communication. Millimeter waves differ from the typical waves that are used in our every-day communications. Millimeter waves have much more higher frequencies. Let's call them, active waves. Thinking about the sinus line again: the highs and the lows succeed each other much tightly. Scientifically we say: millimeter waves have a very short wavelength. Alternatively, one can say: millimeter waves use high frequencies. To give you some numbers: millimeter waves come at frequencies ten to hundred times higher than the ones of your cell phone. Frequencies are between 30 GHz and 300 MHz. And … guess what: their wavelengths are only a few millimeters…

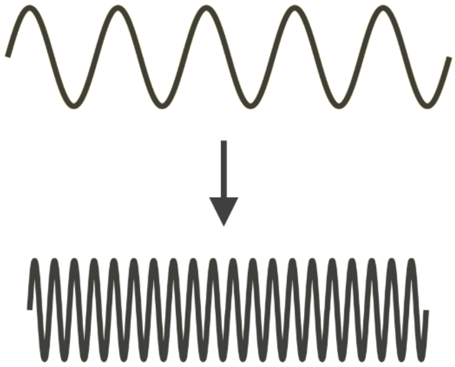
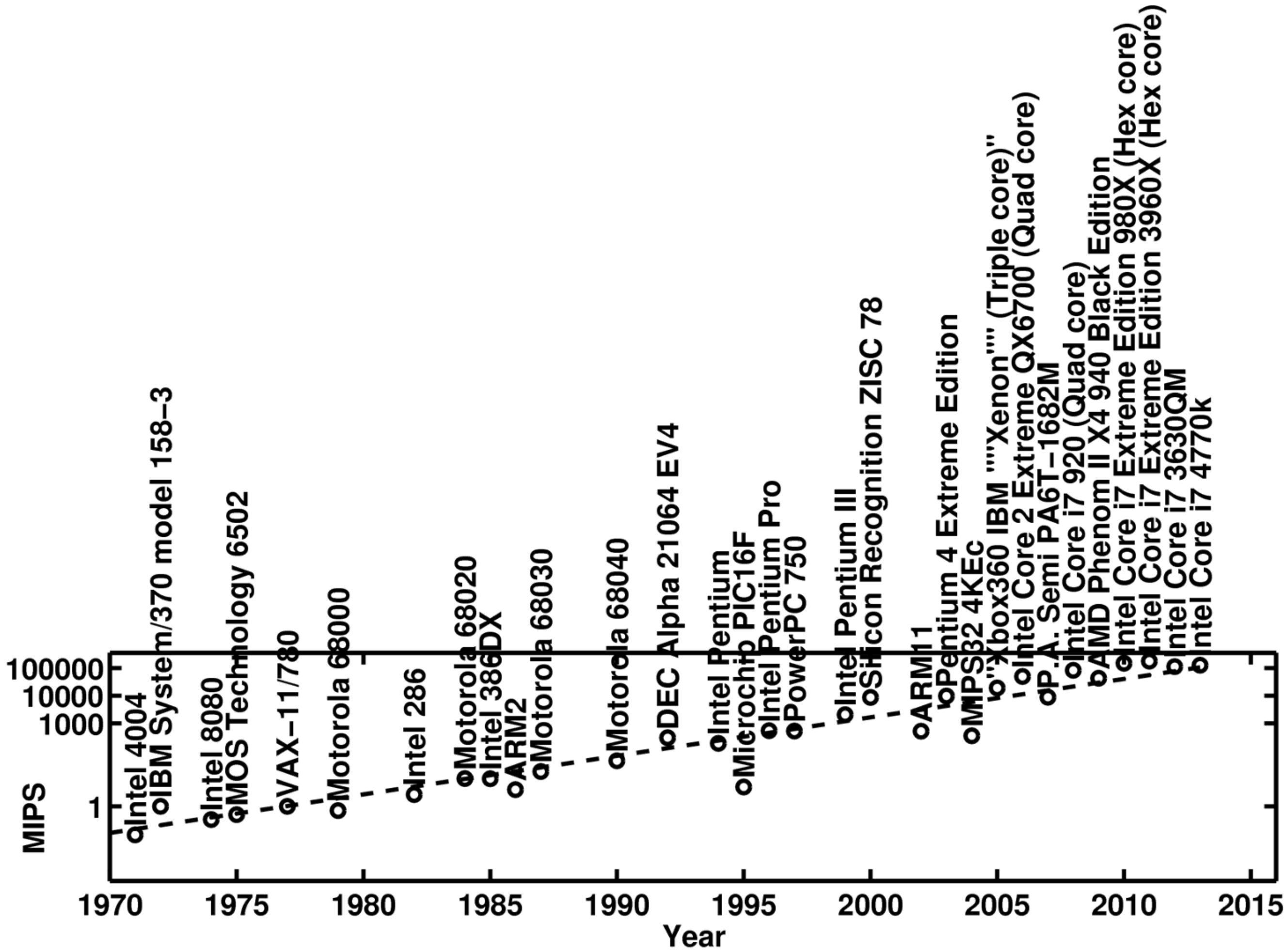


Figure 3: On top: typical waves that your cell phone uses. On the bottom: millimeter waves are much more high-frequency, defining a shorter wavelength than typically used today.

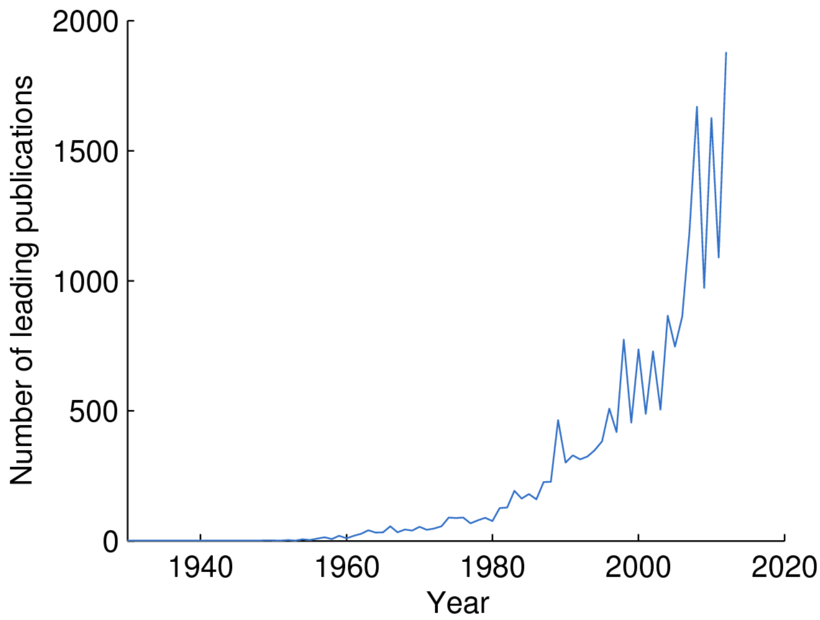
The commercial existence of millimeter waves is thanks to recent advances in electronics. We all know that our smart phone has more computing power than our first desktop PC. The speed of a computer is expressed as a quantity named MIPS[1]. The higher the MIPS-number, the faster the computer. The graph below shows that electronics has become exponentially faster throughout the last decades. Today's processors are about 100000 times faster than the first computer processor on the market, the Intel 4004. Faster electronics means faster electronic circuits and more tools to create these high-frequency millimeter waves. At last, did you know that Gordon Moore, founder and former chairman of Intel, predicted back in the sixties that electronics will grow exponentially? Gordon Moore's prediction was extremely accurate, and therefore the phenomenon that the technology of electronics grows at this enormous rate has generally been referred to as *Moore's Law*.



Figuur 4: The same driver that made computers faster has been an enabler for commercial millimeter waves.

[1] Millions Instructions Per Second

Moore's Law contributed to the research on the advantages of millimeter waves over the decades. Millimeter waves have been researched a lot as the graph below shows. The graph displays the number of publications on IEEE Xplore, the digital library of the world's largest association of technical professionals, having 'millimeter wave' in the publication title.

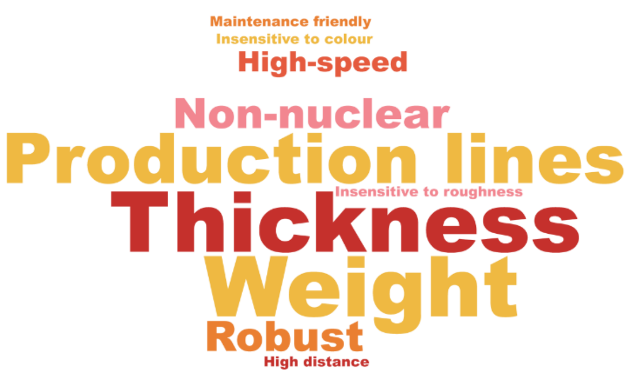


Figuur 5: The number of international publications on the topic of millimeter waves keep on rising

Hammer-IMS believes that both the knowledge database of millimeter waves and the possibilities of electronics have come to a state that industry-relevant measurement systems can be made using millimeter waves.

Is Hammer-IMS the only party providing commercial solutions based on millimeter waves? Luckily enough No. Millimeter waves are used nowadays in a few applications for communication purposes. One typical example is point-to-point links for connecting the cellular network's communication poles to each other, servicing multiple phone calls at the same time and providing a high-bandwidth connection between the poles. The application's name: "cell phone's backhaul connection". Secondly, millimeter waves are applied in developments for streaming HD movies from your cell phone or tablet to your TV-set, enabling smooth images, without distortion or color enable high-definition (HD) movies to be streamed from your cell phone, tablet, … to your TV-set. These applications are an enabler for the activities of Hammer-IMS, since Hammer-IMS is using the same building blocks for its measurement equipment.

Hammer-IMS and millimeter waves



Hammer-IMS offers contactless industrial thickness and weight measurement systems based on its cutting-edge millimeter-wave technology. For these specific applications, there are quite some advantages when millimeter waves are used.

First of all: millimeter waves are non-nuclear, neither radioactive. This might be a straightforward statement. However, currently, thickness and weight measurement in many markets in which Hammer-IMS is active is currently still performed by nuclear or radioactive technology, which is harmful for people and environment. European Basic Safety Standards [8] force European member states to implement a restrictive policy on granting licenses for nuclear installations, among which these nuclear thickness sensors. In Belgium, the FANC [11] controls these licenses and confirms this tendency. This project will contribute to clean and sustainable manufacturing industry conform to these European recommendations by providing new and innovative sensor products to the field of thickness sensing of polymer layers.

Secondly, millimeter wave provide the following performance-related advantages: millimeter waves can penetrate through lots of non-metallic materials, both opaque (irrespective of color) and transparent, but also rough and shiny surfaces. Millimeter-waves are robust when facing fog, dust or changing environmental light conditions.

The principle behind Hammer-IMS's measurement technology is based on the effect that these waves are 'slowed down' by the presence of material. The thicker (or the heavier) the material, the more the wave is slowed down. Many materials' thicknesses or weights can be sensed with millimeter waves, as shown in the figure below.

Material	Geometry
ABS	Sheet
Dry paper	Sheet
EVA (synthetic rubber)	Film
Glass	Sheet
Glass-fiber based composite	Sheet
HDPE	Sheet
Mineral wool	Thick mat
LDPE	Sheet
PA (Nylon)	Film
PE	Foam sheet
PMMA	Sheet
PMP	Film
Polycarbonate	Sheet
Polyethylene-based	Barrier film
PP	Film Non woven Foam sheet
PPS	Film
PTFE	Sheet
PVC-coated paper/textiles	Sheet
PVDF	Film

Figure 6: Materials fitting with the millimeter-wave technology of Hammer-IMS

The measurement principle is shown in the figure below. A signal transmitted from an antenna travels through the material, which introduces an delay to the signal (slow down). After reception in a receive antenna, our state-of-the-art processing electronics analyzes this delay and calculates the thickness or weight of the material from it.

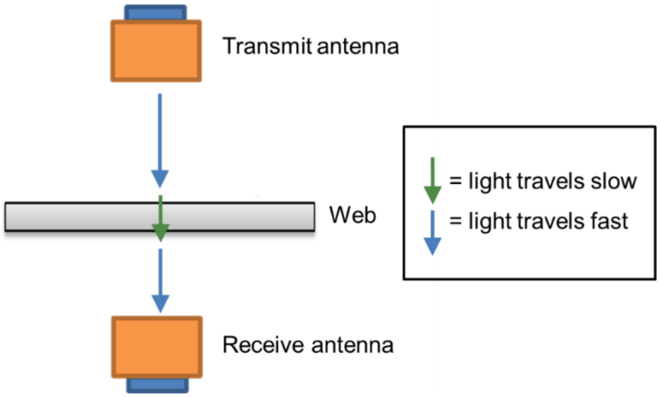


Figure 7: The concept of measuring thicknesses and material weights using millimeter waves

Hammer-IMS's millimeter waves in the plastics converting industry

Millimeter waves are favored in situations where conventional technologies such as optical technologies, nuclear or radioactive radiation, ultrasound waves, inductive or capacitive measurement systems fail, are undesirable or provide an unreliable output. This is especially the case for quality control in the plastics industry.

The plastics industry is a worldwide growing market. An important sub-segment of the plastics industry is the plastics converting industry. This sub-industry converts raw plastic base compounds into (semi)-finished products. Common semi-finished products are all kind of sheet and film products. These kind of materials can be used for the production of packaging of food and beverages (typically after an additional thermoforming application), as construction materials, as protective films (UV-protection, scratch and dust protection), … Many of these sheet and film materials are extruded or cast. The figure below provides a schematic overview on how these films and sheets are typically produced in the plastics converting industry.

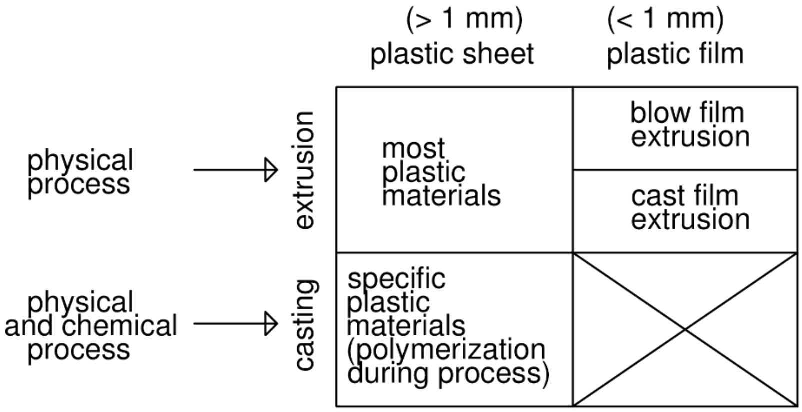
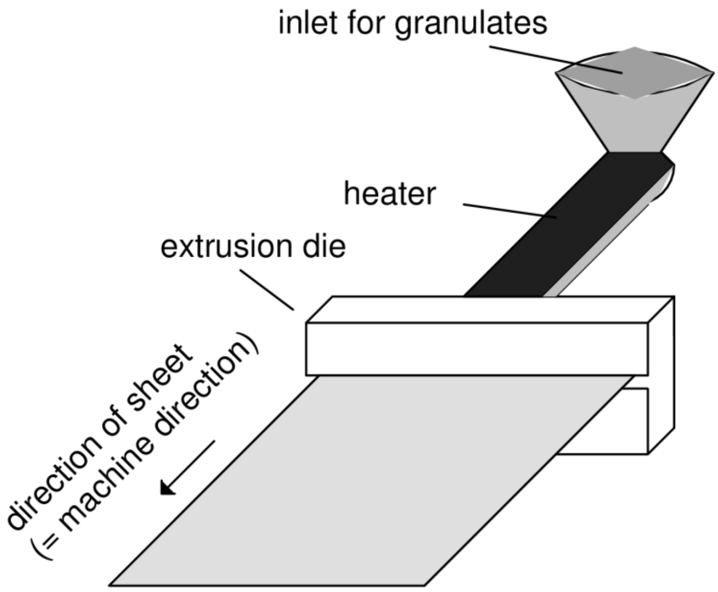


Figure 8: Overview on the split-up in production of sheets and films in the plastics converting industry

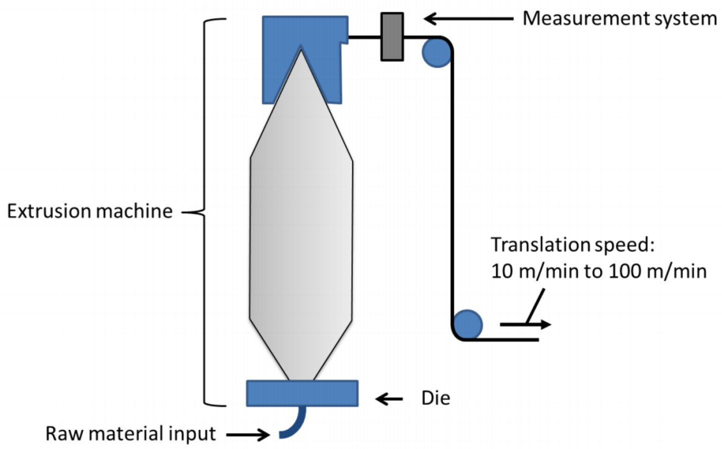
Hammer-IMS considers all planar plastics below one millimeter thickness as 'films'. Planar plastics with thicknesses above one millimeters are referred to as 'sheets'. Sheets can both be extruded and cast. Most well-known plastic compounds are able to be extruded by pushing a fluid plastic mass through a narrow die opening. This plastic mass is obtained by heating plastic base compounds called granulates. This so-called extrusion process creates a plastic sheet after cooling down. Sheet extrusion is a horizontal process as shown in the figure below:



The plastic sheet flows typically very slowly while being extruded. The reason for that is the high thermal inertia. It takes a lot of time before the plastic sheet is solid enough to be cut and stacked. Therefore production line speeds are a few meters per minute maximum (for sheet thicknesses of 10 millimeters ore more).

As an alternative to sheet extrusion, some plastics sheets can be cast. E.g. the compound polycarbonate can be created by pouring liquid base compounds into a tank after which polymerization (the actual creation of the plastic material) is performed. The latter is a chemical process and does not start with heating granulates. Casting is in se a batch process. After having filled the tank, a new tank will be filled. Casting has certain advantages since it enables small production batch sizes. Moreover, it creates plastic sheets that have equal mechanical properties in all directions. Extrusion on the other hand, creates an alignment of the polymer chains, causing non-equal mechanical behavior in both the machine-direction and cross-machine direction. Both plastic sheet casting and plastic sheet extrusion are horizontal processes.

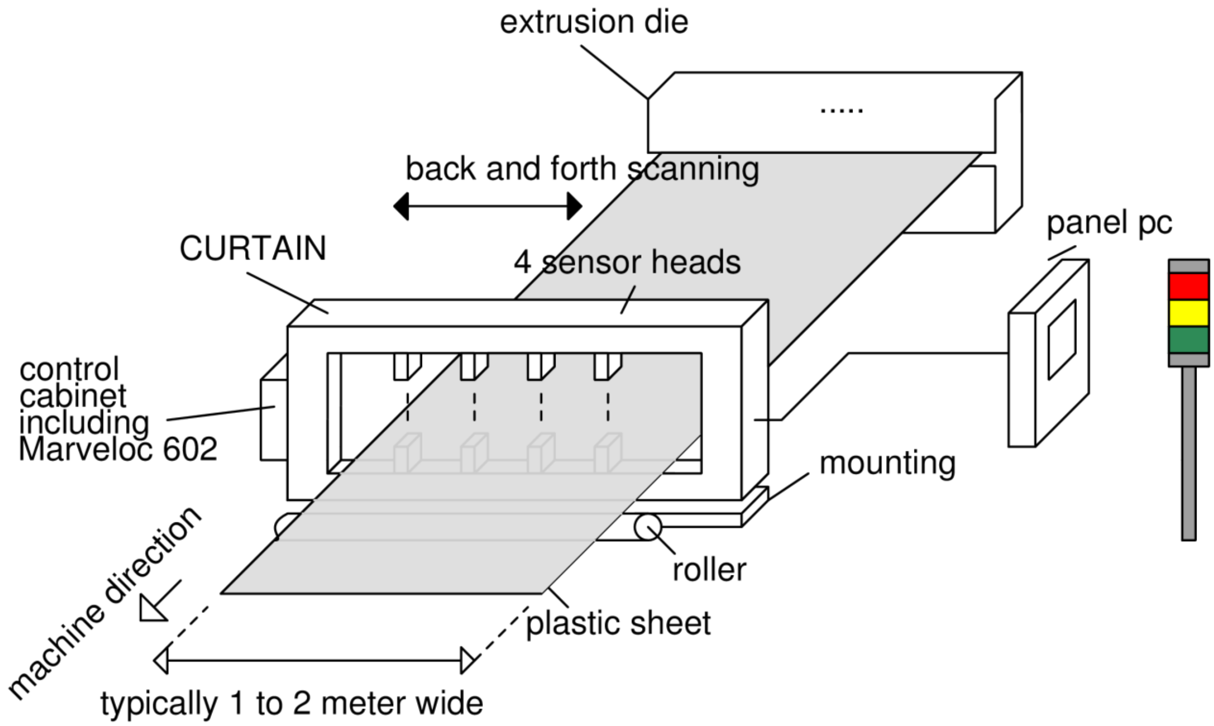
Plastic films, on the other hand, cannot be created by casting. They are always extruded. Extrusion of plastic films can both be of cast-type or of blow-film-type. Note that the terminology ‘cast’ does not have anything to do with ‘casting’, as previously discussed. Cast-type plastic films are created in the same way as a plastic sheet is extruded: granulates are forced through a die opening, but in this case, the die opening is much more narrow than the ones used for plastic sheet extrusion. The blow-film type is a vertical process. It creates plastic films by means of pressurizing an air bubble within plastic material when it leaves a circular die opening. In this way, enormous balloons are created of which the membrane is sold as a plastic film. Blow-film extrusion occurs at high speeds with line speeds up to 100 meters per minute. The reason why these plastics films can be extruded very quickly is because of the low thermal inertia of these thin films. It does not take minutes before the plastic film has become solid and can be coiled up. Therefore, production speeds can be high.



Figuur 9: Blow-film extrusion is a vertical process. The diamond-shaped grey area in the middle of the figure is the balloon-shaped plastic

The conversion process of plastic base compounds to sheets and films is an unstable process. It is easily affected and distorted by many environmental parameters such as temperature and temperature gradients, humidity, pressure, material blends, pulling speeds. Unfortunately, the plastic base compounds and machine hours are very expensive, not allowing plastic converters to play around too much with their machine settings and perform an after-production quality check and throwing away x percent of their products. Therefore, inline thickness measurement is an important concept in the conversion of plastics to sheets and films. However, both sheets and films are non-solid while they are measured and therefore, plastic converters prefer contactless measurement systems.

Hammer-IMS provides these kind of contactless measurement systems. A typical set-up for plastic sheet extrusion is shown below.



Please read the following material for more explanation on this typical solution:

- 20160720_case_plastic_thickness.pdf
- full_solutions.pdf
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- list_of_products_by_hammer-ims.pdf