Sensor-Based Sorting Systems in Waste Processing

Uwe Habich

Steinert Elektromagnetbau GmbH, Köln

Automatische Sortiersysteme für Anwendungen in der Abfallsortierung

Abstract
The technology of inductive, X-ray and color sorting systems is discussed. Principal operation, set-up .and separation results are described.

Keywords
sensor-based sorting, inductive sorting, X-ray sorting, color sorting

1 Introduction

Automatic sorting systems have been used in waste processing for more than 10 years in sorting light packaging (e.g. Duales System Deutschland (DSD) - *Dual System Germany Ltd.*). These systems work with Near-Infrared (NIR-) sensors and can distinguish between different plastics. For the hitherto existing sorting of uncrushed packaging wastes a spatial resolution of several centimetres has mostly been sufficient. In the course of increasing production of refuse derived fuels from commercial or combined wastes more and more alternative sensor-systems which originally come from a field like metal recycling are used for impurity depollution. Furthermore, the crushing of the base material necessary for the material pulping increases the spatial resolution requirements.

Foreign substances in refuse derived fuels are on the one hand inorganic materials like stones, ceramics, glass or metals and on the other hand pollutant-containing organic materials, whereas in this case especially the PVC with a high proportion of chlorine between 30 and 50 weight percent has to be mentioned.

Besides the NIR-sorting, which so far has only been reliably applicable with light or transparent plastics, inductive sorting, optical sorting (mainly by colours) and X-ray sorting are promising technologies for waste processing.

Normally, the applied sorting systems consist of a conveyor road for the separation and steadying of the material, a detector which is placed underneath or above the conveying belt or in the area of the material discharge, and a valve bank which blows out the material component that is to be sorted positively (Figure 1).

The company Steinert offers besides the already widely-used inductive sorting systems also X-ray and colour sorting systems, which due to increasing (secondary) raw material prices become more and more important. Since March 2007 the cooperation in NIR-sorting with the French partner Pellenc rounds off this array of products.

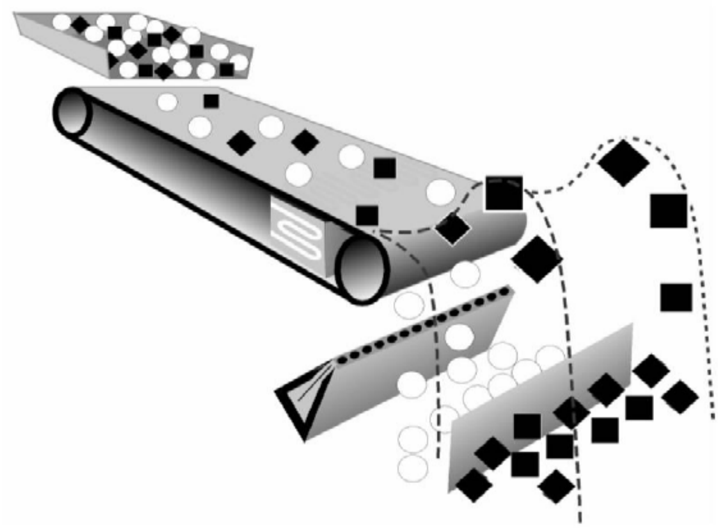

Figure 1 Basic set-up of an automatic sorting system, in this case with an inductive sensor underneath the conveying belt

2 Inductive Sorting

In metal recycling the magnetic separation and the Non-Ferrous Metal Separation (NES) are established technologies. Both of them are mass flow methods in which the material properties of metals (magnetizability and/ or electrical conductivity) are exploited by a (statical or temporally fluctuating) magnetic field constantly attached to the whole width of the material flow. With these methods more than 95% of the magnetizable steel („iron“) and non-ferrous metals are recovered in shredding companies. Latest studies show a recycling rate of 98% [FRANCOIS, 2003].

The metal proportions that are not detected in the magnetic and the non-ferrous metal separation are mainly stainless steel which is neither a good magnetical nor a good electrical conductor. Furthermore, non-ferrous metals from cables or in composites are separated only partially by the above-mentioned methods. In the past, at best a hand picking of larger pieces of metal was carried out in the waste fractions of metal processing plants. The losses in this hand picking are significant. In practical application, only particle sizes larger than 40 mm can be detected, whereas the efficiency with particle sizes of less than 100 mm is strictly limited. The introduction of automatic, sensor-based sorting systems offers for the operator on the one hand the possibility to reduce costs (investment costs and operating costs in contrast to personnel costs), on the other hand the prospect of higher earnings due to a more efficient recovery of residue metals.

The Inductive Sorting System ISS® by Steinert consists of a conveying belt, underneath which a detector strip of adjacent metal detectors with a diameter of 25 mm each is installed near the head pulley. In the area of the discharge there is an air jet strip whose valves are controlled depending on the detector signals. The material is put onto the appliance by a conveyor channel and is separated by the quick-running belt. Due to the velocity difference between conveyor channel (approximately 0.3 m/s) and conveying belt (2.5 m/s) further separation is attained. The conveying belt is 4 m long to ensure a sufficient steadying of the material. The discharger with splitter is formed in that way that false discharge due to rebounding particles is minimized.

The mechanical structure of ISS® is modelled on the proven design of the non-ferrous metal separators, which means that the appliances are specially designed for the rough operating conditions in shredding companies and metal processing plants.

The metal detectors can either be sensors for all metals or stainless steel sensors. Detectors for all metals recognize unspecifically all pieces of metal above the detection limit of approximately 3 mm (ball). Wires are detected reliably up to a diameter of 0.4 mm. With the more complex stainless steel detectors the proportion of stainless steel can be specifically separated from the residual fraction or from a concentrate processed with detectors for all metals. Both detector versions can suppress signals from still left ferrous metal to prevent the contamination of the metal fraction with tire parts with steel reinforcement.

The majority of Inductive Sorting Systems ISS® is currently operated in shredding-plants in North America. In the shredders there less light material is sucked off or separated by air separation than in European plants, which leads to a different composition of the shredding residues. Furthermore, only a small proportion of the material is supplied to sink-float-plants in those plants. With one of the first appliances more than 2 300 t of metal with a purity of > 90% were recovered within one year from wastes which, without the application of ISS® , would have been disposed of [MOSEBACH, 2006]. This corresponds to an equivalent value that exceeds the purchase price of the appliance by far.

In Europe the Inductive Sorting Systems ISS® are used more and more in mature wood and refuse derived fuel processing plants. In contrast to metal recycling the goal here is not to obtain a metal fracture as pure as possible, but to produce a metal-free product to protect following machines. Due to the necessary high volume flux the conveying belt of the ISS® in this case is not coated with a single-grain layer, but with a layer thickness of several centimetres. Product losses in the extraction of a piece of metal are accepted. These losses can be reduced by using a sensor with a track width of 12.5 mm, because then a lot less non-ferrous metal is blown out after the detection of a piece of metal.

3 X-ray sorting

In X-ray sorting the material transported by a conveying belt is X-rayed and the intensity of the transmitted radiation is measured by X-ray line detectors. As the absorption of the radiation depends on both the density of the X-rayed object and the material thickness, the radiation intensity is generally measured in two different energy ranges of the X-radiation (“dual energy“). Due to that the thickness dependency can be eliminated and the material penetrated by radiation can be identified on the basis of its density. This method corresponds to the X-raying of luggage e.g. at airports. Furthermore, X-ray scanners are widely used in the food industry to detect foreign bodies. Moreover, the dual-energy method is known from medical radiography, e.g. for the production of X-ray photographs of bones and soft tissue.

As the object to be identified is completely penetrated by X-rays, the information for the characterization of the material is obtained from the whole volume of an object and not only from the surface, like e.g. in NIR- or colour sorting. Moisture or dust does not lead to a noticeable influence on the measuring results.

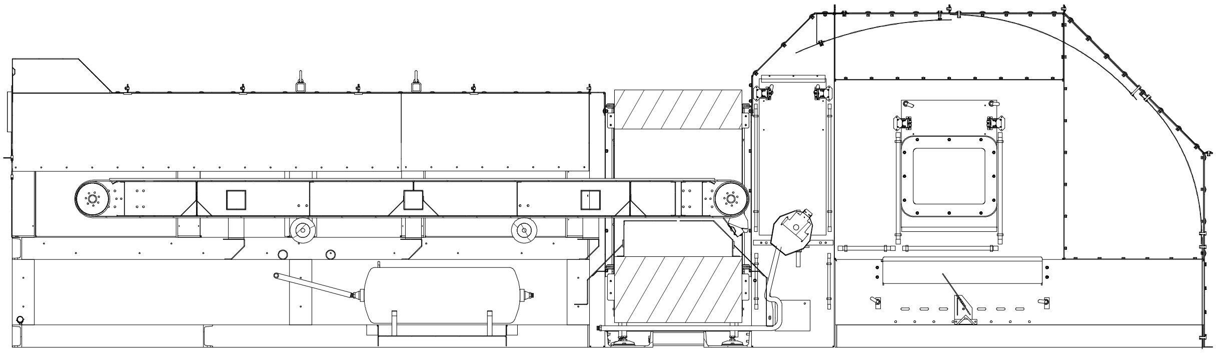

Figure 2 X-ray Sorting System XSS. The actual scanner is displayed by the hatched part.

The X-ray Sorting System XSS by Steinert is shown in Figure 2. The X-ray scanner on the front end of the conveying belt is – similar to the proven Inductive Sorting System ISS® – integrated into an overall system of feeding device (vibrating conveyor), conveying belt and discharge including valve bank. The X-ray source with radiation energy of up to 160 keV is located underneath the conveying belt. The X-ray detectors are installed above the belt. The working width of the XSS is 1,000 mm. The maintenance-free scanning unit is enclosed with lead to be shielded from the direct X-rays emitted by the tube. The X-rayed objects and the conveying belt generate stray radiation which is radiated in all directions in space. This stray radiation is about one factor hundred weaker than the primary X-radiation, so that a couple of millimetres of steel are sufficient for the shielding. Therefore, the XSS is completely cladded with sheet steel and corresponds in its construction to a high protection X-ray device according to the German X-Ray Ordinance. The radiation still measurable outside of the appliance stays below the limit values for full protection X-ray devices. Therefore, no entry restrictions to the prevailing operating location of the XSS are necessary.

In metal recycling the XSS can be used especially for the separation of light non-ferrous metals (aluminium, magnesium) from heavier non-ferrous metals (copper, brass, zinc, stainless steel). Here, aluminium purities of > 95% at flow rates of up to 10 t/h can be reached. The particle size to be processed is approximately 5 to 200 mm. In Europe, complex sink-float plants are currently mainly used for that. Furthermore, a separation between certain cast- and wrought alloys is possible. First results for this application also showed purities of more than 95%, provided that the prevailing alloying proportions (e.g. silicon and copper) lead to a sufficient difference in density.

Another field of application for X-ray sorting is the depollution in “non-ferrous“ processing of secondary raw material. In refuse derived fuel processing the XSS can be used for the separation of PVC. Due to the high proportion of chlorine of between 30 and 50%, PVC has a significantly higher X-ray absorption than other plastics. Dark plastics can also be reliably detected. In processing mature wood the XSS can be used for the separation of inorganic foreign bodies like stones or pieces of metal which otherwise could cause damages to following machines or product impairments. With this application higher layer thicknesses of the material can be tolerated.

For the operation of an X-ray device, type approval specifications normally have to be followed. In Germany, the operation of high protection X-ray devices has to be announced to the competent authority two weeks before start-up. The operator needs a radiological safety agent, whereas for high protection X-ray devices one-day training is sufficient. Furthermore, the plants have to be checked by an expert at start-up and after that every five years.

4 Colour sorting

Colour sorting systems are used very often e.g. in glass recycling and in the food industry. Colour sorting, like NIR-sorting, is a surface-sensitive method. This means that coated or varnished objects in principle cannot be detected in a material-related way. Nevertheless, there are aims in recycling for which colour sorting is an economic solution. This is especially the case in plants where the materials that are to be checked have passed shredding stages beforehand (e.g. shredders in metal processing) that remove the beforehand existing surface coatings or that break up the material in a way that with utmost probability uncoated fracture faces can be observed.

Colour detection systems are known from many fields of production and food engineering. Normally they consist of an illumination unit and a colour camera with CCD-chip (similar to the digital cameras in the consumer sector) or a colour line camera. The latter consists of a linear arrangement of single colour detectors. Detector line and measuring object are moved towards each other with a constant speed. The object is scanned in single lines and the respective measured lines can be put together again to a two-dimensional image. This principle is also applied in colour copiers and scanners.

The colour sorting system FSS by Steinert uses a compact refractive light sensor which is integrated into the necessary number of colour cameras and the illumination. The illumination consists of two rows of white high-performance light-emitting diodes (LED) of which the light is focussed on the observation level by means of cylindrical lenses. LEDs offer, in contrast to the conventional illumination with a multitude of fluorescent tubes, besides the notably more compact set-up essential advantages like a longer life span and a more stable colour temperature at fluctuating ambient temperature. The cameras, which scan a width of 200 mm each, use instead of the older CCD-technology CMOS-chips as colour detectors, which are read out as line detectors. Unlike CCD-chips, in CMOS-technology the electronic evaluation system is integrated on the chip and the single pixels can be read out directly. Due to a special arrangement of the RGB pixels (“Bayer-Pattern“) there is no colour dislocation on the edges of objects. Furthermore, the non-linear characteristic curve of the CMOS-sensors permits reliable colour detection even when single areas of the object of measurement show big differences in brightness. The spatial resolution of the colour sorting system FSS is approximately 0.6 mm. It can sort objects with dimensions starting from approximately 5 mm x 5 mm.

The refractive light sensor is installed above the discharge parabola of the material-feeding conveying belt and observes the material flow against a dark background. The colour pixels of the camera in the red, green and blue spectral range (RGB) have different sensitivities. Furthermore, the light intensity of the LEDs above the observed visible spectral range is not constant. Therefore, a so-called white balance, which can be repeated by the operator if required, is carried out to adjust these parameters.

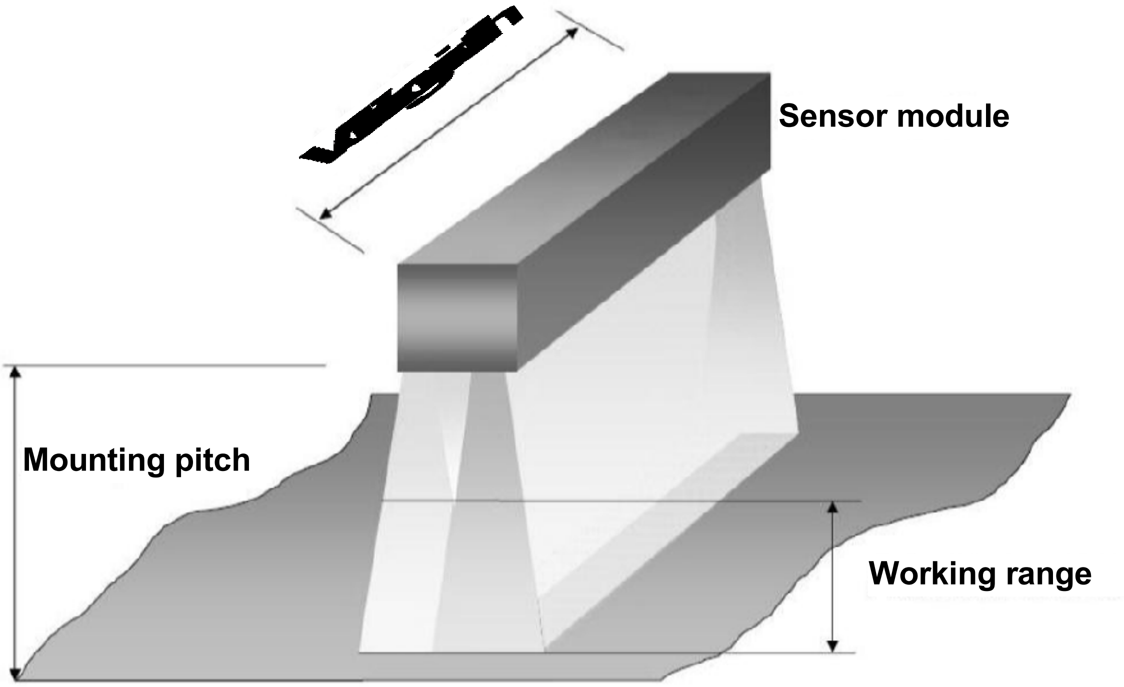

Figure 3 Principle of a compact refractive light sensor. The cameras are arranged between the linear LED units. The mounting pitch in the colour sorting system FSS is 470 mm. The working range in which the cameras "see" sufficiently sharp is more than 100 mm.

In a teach-in process, the camera system has to be programmed in order to know which colours are to be assigned to which class of material. For that purpose, the intensity values of the prevailing colour pixels (RGB-mode) are converted into the HSV-mode (**h**ue, **s**aturation, **v**alue). Hue and saturation can then be depicted as a colour circle in which different areas are assigned to the individual classes of material. This happens by surveying clearly assignable sample objects.

After the magnetic-, non-ferrous metal- and X-ray separation (alternative to sink-float separation) in the recycling of shreddered metals there is a mixture of the heavy non-ferrous metals copper ("red"), brass ("yellow") and zinc/stainless steel ("grey"). With this application, the sorting with the colour sorting system FSS reaches purities of > 95 % with a discharge of significantly > 90%. The flow rate is more than 10 t/(h*m). With this method objects, which cannot or only with difficulty be assigned to a certain material with the naked eye, are detected reliably. As a surface method, colour sorting has, however, its limitations: e.g. rusty pieces of iron can only hardly be distinguished from copper. With an effective pre-separation of iron, it should definitely be possible to keep this contamination within limits.

In processing electronic waste the application of colour sorting can be considered for the separation of circuit boards from a "metallic" fraction.

5 Summary

Besides the in waste processing already established NIR-sorting systems, meanwhile further sensor-based sorting systems are available, which originally have been developed for other fields of use in recycling and which are now used more and more often in refuse derived fuel processing plants. This includes inductive sorting systems, which use metal detectors with high spatial resolution for the separation of metallic and non-metallic proportions of bulk material. For this case the ISS by Steinert is available with a sensor for all metals and a selective stainless steel sensor. For the separation of light and heavy non-ferrous metals, the X-ray sorting system XSS can be used, in which the material supplied by a conveying belt is X-rayed and the material is characterized by means of the specific radiation absorption. This device is suitable for the depletion of PVC in waste processing. With the colour sorting system FSS non-ferrous metals can be separated from one another or circuit boards can be separated optically from a metal fraction.

6 Literature

Francois, O.	2003	International Automobile Recycling Congress Geneva, March 12. – 14. 2003
Mosebach, J.	2006	Symposium Sensor Based Sorting, Aachen, Germany, March 28. – 30. 2006

Author's Address

Dr. Uwe Habich
Steinert Elektromagnetbau GmbH
Widdersdorfer Straße 329-331
D-50933 Köln
Telephone +49 221 4984 190
Email: habich@steinert.de
Website: www.steinert.de