THE BRAINS OF BANKNOTE PROCESSING SYSTEMS

Engineers and physicists at Giesecke+Devrient Currency Technology are using multiphysics simulation to develop magnetic, optical, and ultrasonic sensors for high-performance modular banknote processing systems that can securely sort and process millions of banknotes every day.

By **ZACK CONRAD**

THE PHRASE "CASH IS KING" may reverberate with many of us, but not nearly as much as it does with professional cash centers that process and handle millions of banknotes every day. There is more cash in circulation today than ever before, and this surge in volume, coupled with the growing variety in banknote security features and increasing complexity in banknote design, has drastically raised the requirements for automated cash handling systems. All around the world, printing plants have to guarantee the highest possible quality of each freshly printed banknote. Furthermore, central and commercial banks and cash-in-transit companies face the need to sort banknotes based on denomination, currency type, orientation, authenticity, and degree of fitness with astounding speed and accuracy. Jan Domke and Klaus Thierauf, physicists at Giesecke+Devrient (G+D) Currency Technology, develop sensors for modular, high-performance banknote processing systems (BPS) for these professional cash centers (Figure 1).

To lower processing costs and ensure secure output of the processed banknotes, G+D Currency Technology's processing systems use extensive arrays of sensors that guarantee reproducible results and lasting durability. Banknotes are fed into the machine and transported through a round belt conveyor system (Figure 1, left), that permits full-face measurement on both sides of each banknote. Decisions regarding sorting are made by a variety of sensors along the way. Counterfeit banknotes are rejected reliably, whereas unfit banknotes, due to their insufficient quality, are separated or even shredded. Banknotes passing the inspection are bundled together and returned to the cash cycle or bank vault. A typical machine made by G+D Currency Technology can detect a multitude of different currency types in all four physical orientations in a single run. The fastest systems can process more than 150,000 banknotes per hour. "In our department, we develop the sensor systems and evaluations that are responsible for classifying banknotes to counterfeits or authentic and fit or unfit," Domke says. "They are the eyes and brains of these machines."

SENSING AND SORTING

WHEN TRAVELING THROUGH the processing system, the banknotes are exposed as three main sensor systems: magnetic, optical, and ultrasonic sensors. The different sensing properties are used in conjunction with each other to seamlessly and efficiently inspect and sort banknotes. Magnetic sensors detect special imprinted magnetic security features; optical sensors operate in the UV, NIR, and visible range to classify bills based on denomination and currency types, and ultrasonic sensors verify fitness requirements (tears, holes, tape, etc.). Domke and Thierauf, as part of their team's continuous developmental work to sharpen sensor performance, use multiphysics simulation to better comprehend the complex underlying physics. As an important step in the development process, simulation is used to prove principal

Figure 1. The BPS X9, the fastest banknote processing system in the world, has a processing speed of 44 banknotes per second and can achieve an effective throughput of more than 150,000 banknotes per hour. The dimensions of the central module are 1.9 m x 5.7 m (H x W).

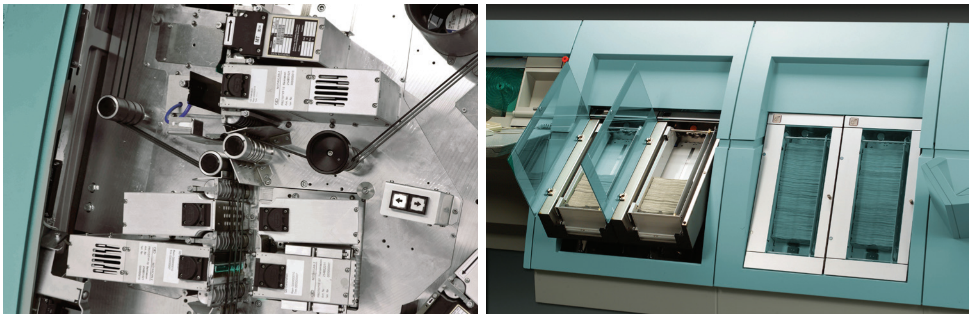
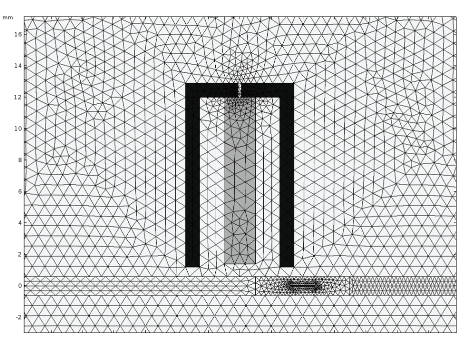


Figure 2. Left: Part of the sensor section with a round belt conveyor system that transports the banknotes through the banknote processing system. Right: Sorting banknotes into the large delivery module is an option to provide loose banknotes, for example, for filling cash dispensers.

ideas, which can then be discussed, for example, with the algorithm development team. “The COMSOL® software is a very important tool to get the entire team on the same page with their visualizations and understanding of the physics effects at play,” Domke says. “It is an essential part of the sensor development process.”

DETECTING SECURITY FEATURES

A CRITICAL SECURITY FEATURE of banknotes is the magnetic ink imprinted on them. The ink acts as a magnetic probe. As the bill travels through the transport system, the probe will interact with the guided field of permanent magnets in the sensors. They can then analyze the effects on the field lines as a signal in real time and yield information according to specific algorithms. In order for the algorithms to be accurate,



readings of the changes in the magnetic field need to be simulated beforehand. Thierauf uses numerical simulation to model this behavior. By setting up the assembly of the magnetic sensor with a predefined magnetization in the software and using a moving mesh technique to model the passing by of the soft magnetic probe, they can create magnetic readings and tweak parameters to tailor the field geometry to their needs.

When the probe passes by the sensor, there is an interaction of the probe with the magnetic field. The magnetic sensor will sense the change in the magnetic field and the resulting signal comes out of the system as an electrical response. The signal amplitude depends on the distance of the probe from the magnets, and simulation is critical for understanding this dependence. “When you form the resulting magnetic field, you can calculate the dependency on the distance,” Thierauf explains. “From there, you can optimize and apply it to more specialized models based on customer specifications.”

ADHERING TO FITNESS REQUIREMENTS

IN ADDITION TO security features, banknotes also need to be sorted based on their adherence to fitness requirements. Banknotes may be ripped or torn; have missing or folded corners, stains, graffiti, or tape; or be stuck together with other banknotes. For example, to help detect banknotes that are stuck together or have tape on them, Domke’s team employs arrays of ultrasonic sensors. When a bill arrives at the sensor, a pulsed ultrasonic acoustic signal is sent through it to a receiver on the opposite side of the bill. The major difficulty of this is that only 1% or less of the signal actually travels through the banknote and reaches the receiver; 99% of the acoustic energy is reflected. 24 pairs of transmitters are employed in the system to increase the resolution at the receiver

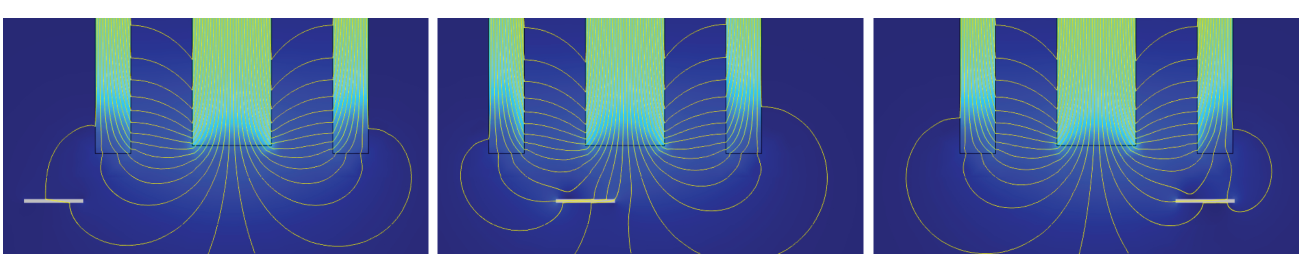


Figure 3. Simulation of a magnetic probe passing the magnetic sensor. Top: Permanent magnet (gray) and iron cores (black) guide the magnetic field of the sensor. A moving mesh is used to model the probe passing by in a virtual transport channel. Bottom: Time sequence of the probe passing by the sensor and deforming the magnetic field.

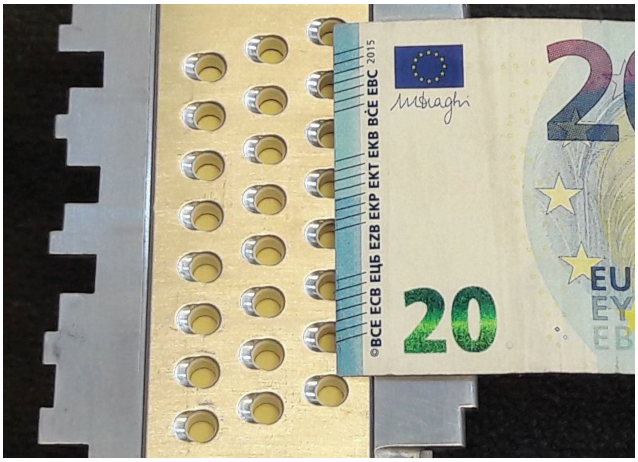


Figure 4. Array of 24 transmitters used to send ultrasonic acoustic signals through banknotes. A 20 euro bill is shown.

(Figure 3). However, with this many transmitters, signal interference becomes a problem and creates a complex and delicate issue of managing signal timing, damping elements, and geometry aspects.

Domke and his team utilize multiphysics simulation to manage these challenges. As the bill passes by and the ultrasonic signal is reflected, parts of the reflected pulse will run around the edge of the banknote due to diffraction and therefore be picked up by the receiver (Figure 4). As this signal would interfere with the weak signal of the transmission, the detection process by the receiver needs to be finished before the diffracted signal arrives. Using multiphysics simulation Domke modeled the addition of acoustic channels to guide the pulsed signal. By simulating both the near and far field characteristics, the maximum amplitude, and the decay of the acoustic field, he was able to prevent the distortion of the transmitted signal. “Simulation is an essential tool here because at such small scales, experimental measurements are impractical,” Domke explains. “If we can tune the geometry and timing just right via simulation, we can get really good and undisturbed transmission information from the inception of the design.”

» FUTURE IMPROVEMENTS

DOMKE AND THIERAUF also use multiphysics simulation for other aspects of sensor development and will continue to expand their simulation capabilities. They employ a multiphysics approach to modeling ultrasonic transducers and conduct heat transfer analyses for thermal management in their printed circuit boards. For these applications, they can also compare their simulations with experimentation, and the agreement has been extremely convincing of the accuracy of their models. They hope that continued use of simulation will yield higher degrees of flexibility for customer specifications, optimal sorting out of potential counterfeit bills, and maximal alignment of fitness inspection with human perceptions. ◎

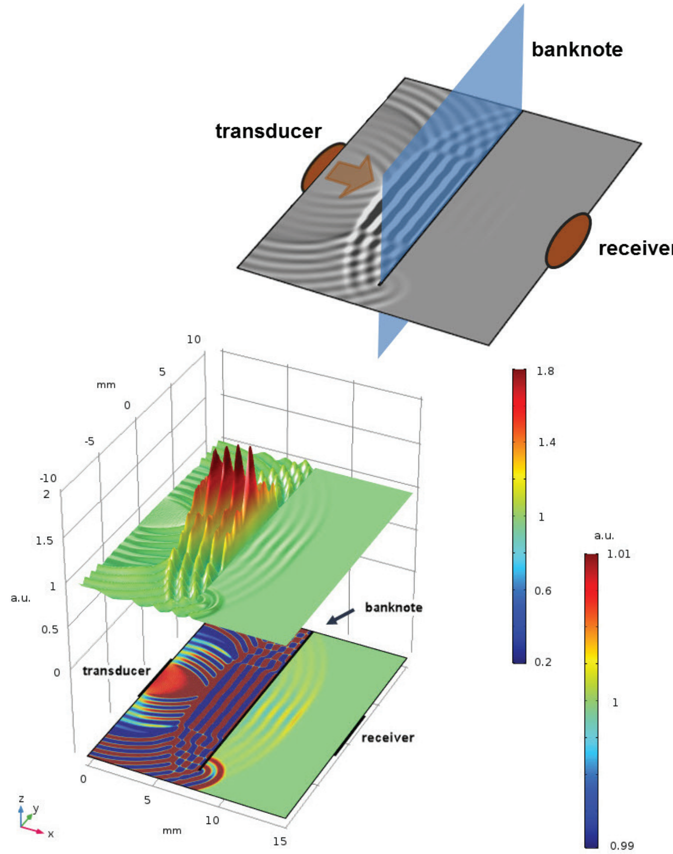


Figure 5. Propagation of an acoustic wavelet from the transducer toward the edge area of a banknote and to the receiver. Top: Sketch of the simulated setup. Bottom: Two different representations of an acoustic wavelet propagation toward a banknote. Here, half of the wavelet already impinged the note. Only a small fraction is transmitted, whereas the major part gets diffracted around the edge of the banknote.

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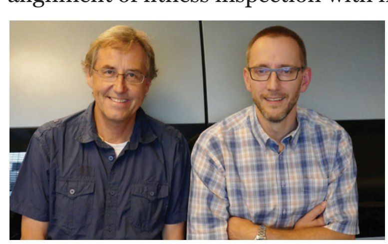

Klaus Thierauf and Jan Domke, physicists at G+D Currency Technology.