THE ELEPHANT IN THE ROOM – WHAT DOES INDUSTRY 4.0 REALLY MEAN IN THE FORGING INDUSTRY?

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Industry 4.0, often described as the "Fourth Industrial Revolution" represents a fundamental change in manufacturing driven by digital innovation. It is described as *the integration of physical production processes with digital technologies such as the Internet of Things (IoT), big data analytics, and AI.* This convergence results in "SMART factories" where systems communicate autonomously, and data flows freely across the production landscape. Sounds ingenious – and complicated.

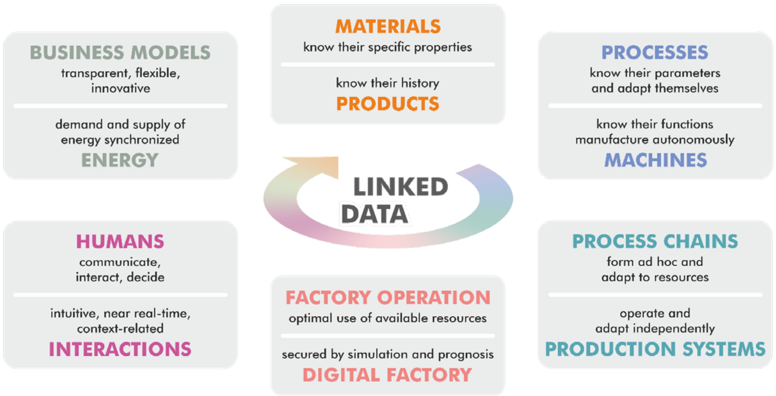

Figure 1: Linked data in manufacturing organization.

What Does Industry 4.0 Look Like in a Forge Shop?

Many of us in the forging industry are familiar with traceability requirements, pyrometers, vision cameras, and tonnage monitors. But does that count as Industry 4.0? And at what point is a forge shop considered a SMART Factory? These are important questions to answer when evaluating your current production and future growth.

Industry veterans often refer to the forging process as, *"The Art of Heat It & Beat It."* Technically speaking, this means that a billet is shaped largely via compressive loading into a desired state. To transform the billet into a forged product, several operations are needed such as shearing or saw cutting, billet preparation, heating, preforming or bending, forging, trimming, cooling or heat treatment. All these operations exhibit subsystems such as tooling, lubrication with their own subsequent variances, and nonconformities that directly influence product quality and cost.

Industry 4.0 takes this time-tested manufacturing process to a new level of efficiency and precision. It targets enhanced process monitoring and establishes defined codependence between operations to recognize and mitigate non-conformances. Integrated AI predicts long-term trends and potential risk of non-conformity. This greatly improves control of the manufacturing operations, increases competitiveness, reduces downtime and cost.

In recent years, Europe has become synonymous with digital transformation in manufacturing while adaptation to Industry 4.0 in the U.S. has been rather slow. Europe's success in this realm is evident in how manufacturers have embedded technologies like inline quality monitoring and hot part measurement directly into their production lines. These technologies have elevated product quality and paved the way for greater efficiency in supply chains and production workflows. European institutions, particularly the Germany-based Fraunhofer Society, have played a critical role in bridging the gap between research and industrial application, to ensure that groundbreaking technologies quickly transition from the lab to real-world production environments.

Italy-based FICEP, one of the world's leading press manufacturers, has integrated Industry 4.0 technologies within their products. From advanced sensors, real-time data analytics and artificial intelligence (AI), to interconnected cyber-physical systems, these innovations have set benchmarks in forge product quality, production efficiency, and operational agility.

Let's look at some of these digital technologies.

Adopting digital tools in forging and forming processes vastly enhances quality, efficiency, and competitiveness. This process already begins at the component development stage. Using simulation-based component design, forged parts can be developed and engineered to suit manufacturing requirements, ensuring optimal die filling during forming and minimizing tool wear through an optimized sequence of forming stages. What's more, continuous process simulation enables the prediction of part properties. Based on these results, components can be geometrically optimized in reverse under given boundary conditions. The following image illustrates such a development sequence.

Figure 2: Optimized production with digital tools.

Let's look at inline quality monitoring systems as an example. This effective monitoring system can continuously inspect production in real time, promptly detecting defects and allowing for immediate adjustments. This not only reduces waste but also ensures that every component adheres to rigorous quality standards.

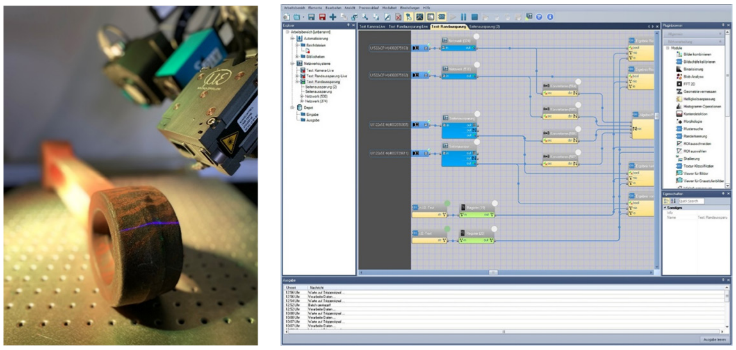

Figure 3: XEIDANA - Multi sensor inline quality inspection system by Fraunhofer IWU, Germany.

Hot part measurement technologies offer another significant advantage, by providing accurate dimensional data on components that are still at elevated temperatures. This capability is particularly crucial in forging, where rapid and precise measurements help to predict proper part quality.

Press load monitoring is a domain where digital innovation can make a profound impact. By installing sensors on mechanical presses, manufacturers can continuously track operating loads. This real-time data supports predictive maintenance strategies, allowing potential issues to be identified and addressed before they result in unplanned downtime. The overall effect is a smoother production cycle, longer equipment life, and better resource utilization.

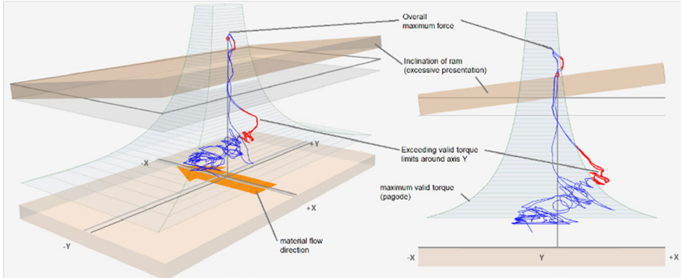

Figure 4: Live view press load monitor system identifying overloads of mechanical presses, developed at Fraunhofer IWU.

At the core of these advancements is the ability to collect and analyze data across the entire production process. Centralized data hubs gather input from a variety of sources, including machines, tools, an ERP system, and the human within the process chain. In concert, these elements facilitate a comprehensive digital overview.

Applying statistical tools to the collected data to create a visual job performance or machine downtime analysis, are widely used approaches. To illustrate some of the applications, we will use an exaggerated example of tonnage values for three different forging processes over their past several production runs.

The graph below shows a box plot of average tonnage measured for three different parts over their last six production runs. Cluster 1 shows that one setup with subsequent production resulted in an average max tonnage of 34 tons for this specific run.

The lowest average tonnage of eight tons was measured for another production lot.

The median tonnage of all six runs lies at 23 tons. The statistical 75% percentile lands at 27 tons and the 25% percentile lies at 15 tons.

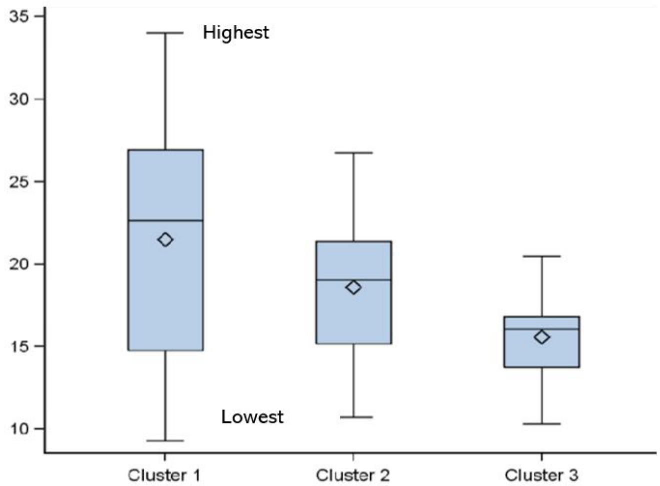

Figure 5: Press tonnage data for three different products over six production runs.

Cluster 1 shows the largest variation amongst the three different forged parts. Widespread tonnage variation in forging operations, among other things, can indicate setup variation, (e.g., ram adjustment too far down or the billet weight varies too much from lot to lot). Industry 4.0 methods apply such information to automatic system adjustments and prediction of outcomes. In our case, one outcome among many might be that the system increases hot part inspection frequency for underfill if the tonnage is detected below the predicted value from historical data and FE Simulation outputs.

In the case of Cluster 3, a very narrow tonnage variation is observed. This indicates that the process is under control and repeatable.

The benefits are clear. These advanced analytics and application of AI-based evaluation mechanisms, manufacturers can:

- Enhance root cause analysis and risk mitigation.
- Predict and preempt machine failures.
- Optimize process parameters based on historical and real-time data.
- Implement adjustments dynamically to maintain quality and performance.

The Role of the Fraunhofer Society, FICEP and Campbell Press Repair

The Fraunhofer Society in Germany is renowned for its expertise in bridging the gap between academic research and industrial application. Through collaborative projects, technology transfer, and consulting, Fraunhofer has contributed significantly to advancing Industry 4.0 practices in Europe. American manufacturers could greatly benefit from a similar approach. The adaptation of European best practices and standards—especially those developed by institutions like Fraunhofer—can provide U.S. companies with proven frameworks for digital transformation.

A local champion in this space is Campbell Press Repair in Lansing, Michigan and Official Partner of FICEP in the United States. With deep roots in the region's manufacturing sector, Campbell is uniquely positioned to adopt and promote Industry 4.0 technologies. By integrating inline data acquisition with sensor networks and implementing predictive maintenance routines, Campbell Press Repair can help modernize forging producers' operations and serve as a model for other U.S. manufacturers. The company's initiatives spark broader industry momentum, encouraging collaborative partnerships with local manufacturers, technology providers, and academic institutions.

Some key initiatives for Campbell Press Repair include:

- **Implementing Digital Monitoring:** Upgrading existing presses with sensors to collect real-time load data and performance metrics.
- **Collaborative Pilot Projects:** Partnering with regional manufacturers to test new solutions in inline quality monitoring and predictive maintenance.
- **Workforce Development:** Investing in training and upskilling programs to equip employees with the skills required for a digital manufacturing environment.

Addressing U.S. Market Deficiencies

For the U.S. manufacturing sector to fully embrace Industry 4.0, several deficiencies need to be addressed. First, legacy infrastructure must be upgraded to support modern digital ecosystems. This involves not only installing new hardware but also developing software capabilities that enable seamless data communication across different production systems.

Moreover, the fragmented nature of current data collection methods poses a significant obstacle. Without a unified digital platform, the potential of inline quality monitoring or hot part measurement is severely limited. U.S. companies must work toward integrating disparate data systems into centralized hubs that provide real-time insights into every facet of production.

Another area of concern is the human factor. A substantial gap exists between the digital skills required by modern manufacturing and the current workforce's capabilities. Addressing this gap will require a concerted effort from educational institutions, industry groups, and government agencies. For instance, targeted training programs and vocational courses that focus on IoT, AI, and data analytics can prepare the workforce for the upcoming digital revolution.

Strategic Roadmap for Digital Transformation

The transformation toward Industry 4.0 is not an overnight process; it involves a series of strategic steps aimed at integrating technology and fostering a culture of innovation. A well-defined roadmap can guide U.S. manufacturers on this journey. Such a strategy might include:

- **Assessment and Planning:** Conducting a thorough evaluation of existing production systems to identify deficiencies and areas where digitalization can yield the greatest benefits.
- **Pilot Projects:** Initiating small-scale projects in critical areas like inline quality monitoring and press load management to demonstrate the value of Industry 4.0 technologies.
- **Investment in Infrastructure:** Prioritizing the upgrade of legacy systems and the development of centralized data architectures to facilitate real-time data collection and analysis.
- **Workforce Training:** Implementing robust upskilling programs to ensure that all levels of the organization are capable of operating and maintaining new digital systems.
- **Collaboration and Partnership:** Engaging with external experts such as the Fraunhofer Society and local industry leaders such as Campbell Press Repair to share best practices and drive innovation collectively.

By following this roadmap, U.S. manufacturers can gradually transition toward a more integrated, efficient, and competitive production paradigm. The benefits are clear - a more agile and responsive manufacturing process, reduced waste and downtime, and higher overall quality contribute to a stronger competitive position in the global market.

Conclusion

Industry 4.0 presents a transformative opportunity for U.S. manufacturing, particularly in the critical fields of forging and forming. While Europe has set a high standard through the successful integration of digital technologies, the U.S. industry still has substantial progress to make. The path forward involves addressing legacy infrastructure challenges, unifying fragmented data systems, and bridging the digital skills gap through targeted training and investment.

Collaboration with global institutions like the Fraunhofer Society and FICEP, combined with the efforts of local pioneers such as Campbell Press Repair in Lansing, Michigan, can serve as a catalyst for change. These partnerships offer a blueprint for how technological innovation can be harnessed to not only overcome current deficiencies but also to drive new levels of efficiency, quality, and market competitiveness.

Ultimately, the shift to Industry 4.0 is about more than technology—it is about fostering a new culture of innovation and continuous improvement. By embracing digital transformation, U.S. manufacturers can ensure that they remain at the forefront of industrial progress. The time to act is now; with strategic investments, collaborative efforts, and a commitment to innovation, the U.S. manufacturing sector can transform its forging and forming operations into a model of modern industrial excellence for the 21st century and beyond.

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