# Individual Die Load Analysis Using a Standard Tonnage Monitor

Qingyu Yang, Qiang Li, and Judy Jin - Department of Industrial and Operations Engineering
The University of Michigan, Ann Arbor MI

Industry Partners: HHI Forging Royal Oak, OG Technologies

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## 1. Objective

In general, a complex forging process consists of multiple forming stations. It is in most cases not economically viable to directly measure each individual station. Generally, four tonnage sensors are installed on four columns of a forging press to measure total tonnage to ensure the press itself is not overloaded. In this research, a new method is developed to draw conclusions on individual die loads, their fluctuation and significance on process variation. Different from existing tonnage monitors, using the sum of four sensor measurements, this research is for the first time to fully utilize the extra information from individual four sensor signals. The case study is performed at HHI Forging, Royal Oak, MI on a 5 station Kurimoto press to detect abnormality in individual stations and their relevance on product quality.

For the purpose of estimating individual source signals (load on each station) from the mixed sensor signals (tonnage monitor) when their linear relationship is unknown**,** Independent Component Analysis (ICA) and Sparse Component Analysis (SCA) are two general methods studied in the literature. The ICA method is effectively used for separating the mixed sensor signals into individual source signals with the assumption that the source signals are statistically independent and non-Gaussian. Differently, the SCA method can be used to separate the dominant source signals from the mixed sensor signal no matter whether they are dependent or not.

## 2. Project Description

The developed methods are applied to a multi-station operation forging process illustrated in Fig. 1. A forging is produced in 5 hits – skip feeding: Free upset, blocker, finisher, piercing, and trimming. Fig. 2 shows the source signals generated by these five die operations. Based on the engineering design, it is known that the source signals include two independent source signals generated by station 4 (piercing) and station 5 (trimming), and three dependent source signals generated by stations 1~3. From Fig. 2, it can be seen that the magnitudes of the independent source signals of stations 4 and 5 are much smaller than those of the dependent source signals from stations 1~3. Therefore, either single ICA method or the SCA method cannot be used to fully separate the source signals from mixed sensing signals.

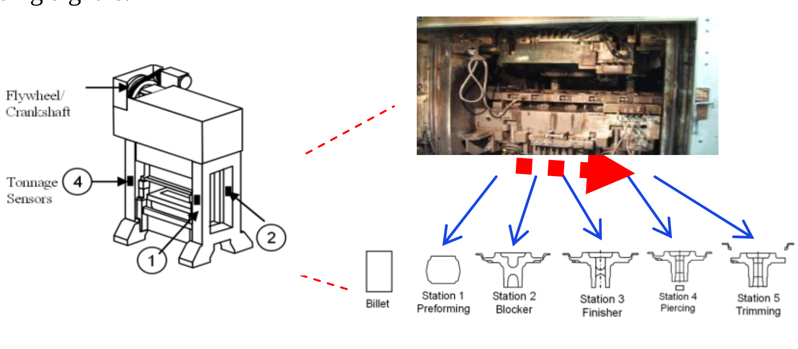


Figure 1: A multiple operation forging process with five operations

During continuous production, strain gage sensors are usually installed on the linkages or columns of the forging press to measure the press tonnage forces. The force measurements from the gage sensors can be reasonably considered as a linear combination of the die forces of each station. In this case study, in order to fully separate five die forces, five sensor signals must be installed, otherwise only four die forces can be separated. In order to demonstrate the proposed methodology, we generated two arbitrary sensor mixture matrix $\mathbf{A}^I$ and $\mathbf{A}^D$ for five sensors, which is used to demonstrate the generality of the proposed method applicable to an arbitrary sensing system independent of sensor locations. Figure 3 shows the surrogated sensor signals using corresponding sensing mixture matrix $\mathbf{A}^I$ and $\mathbf{A}^D$.

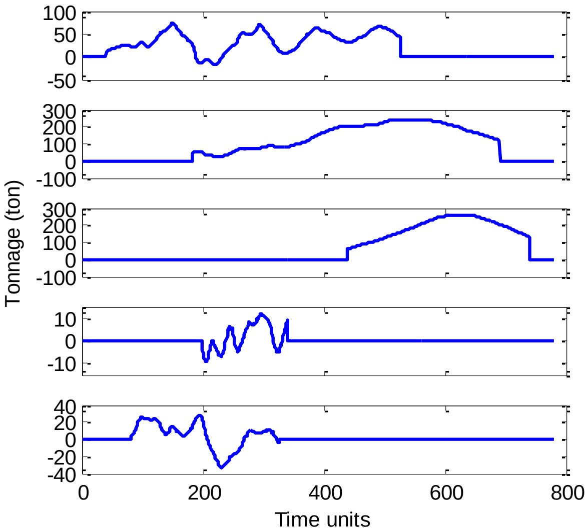


Figure 2: Source signals generated by five die operations

$$\mathbf{A}^I = \begin{bmatrix} .66 & .58 \\ .36 & .94 \\ .85 & .39 \\ .93 & .66 \\ .68 & .97 \end{bmatrix}, \quad \mathbf{A}^D = \begin{bmatrix} .40 & .26 & .14 \\ .28 & .17 & .92 \\ .55 & .96 & .32 \\ .26 & .49 & .79 \\ .46 & .70 & .36 \end{bmatrix}$$

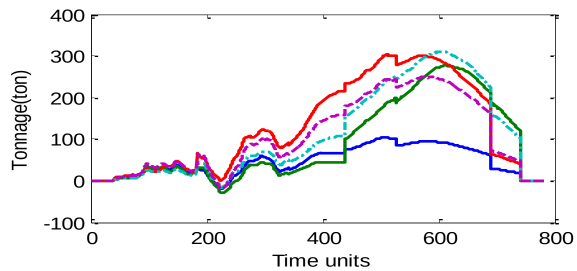


Figure 3: Simulated mixed sensor signals

Suppose abnormality happened on the first and the fourth dies and the corresponding faulty die signals are illustrated in Fig. 5. The estimated independent and dependent die signals are illustrated in Fig. 6. It can be seen that both the independent faulty die signal and the dependent fault die signals are successfully estimated.

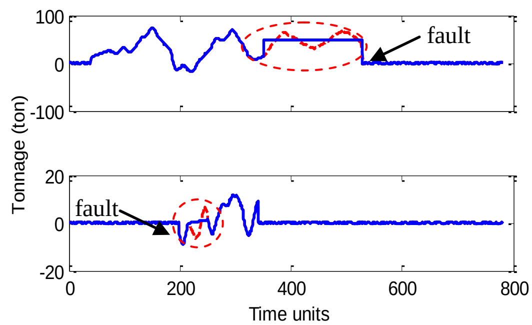


Figure 5: Fault source signals

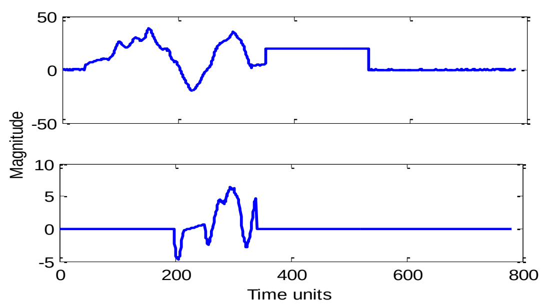


Figure 6: Estimated fault source signals

## 7. Summary

This research proposed a new method for estimating the individual die signals from the multiple tonnage sensor signals by combining the Independent Component Analysis (ICA) method, the Sparse Component Analysis (SCA) method, and the engineering knowledge. The newly developed method consists of two major steps: first, the ICA method is applied on multiple tonnage sensor signals. The impacts of the independent die signals on the measured sensor signals are then eliminated. The reduced sensor signals are separated using the SPC method in time and frequency domains. Furthermore, two statistical rules are developed to check the sparse property and to monitor the individual operations based on the estimated source signals. A case study on a forging process is conducted to demonstrate the developed methods. The case study showed that the independent/dependent die signals can be successfully estimated by the proposed estimation method, while neither the ICA method nor the SCA method can deliver satisfactory results. The estimation of the source signals offers efficient monitoring and quality assessment of the individual die operations, thus enhancing the diagnosability of the tonnage monitoring system.