Investigations of different loading conditions in a high speed mechanical press

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Industrial Summary

At high operating speeds, usually greater than 200 strokes per minute (spm), mechanical presses exhibit dynamic effects that may influence the process conditions. In order to maximize the advantages of high speed presses and maintain reproducible part quality, it is necessary to monitor and understand these dynamic phenomena. To study the behavior of a high-speed press under various loading conditions, a series of experiments was performed with a mechanical high speed press. This press is capable of reaching stroke rates up to 1200 spm.

The goal was to simulate several real process loading conditions, by means of calibrated load cells, in order to monitor the dynamic behavior of the press. Changes in shutheight, load, and slide deflection were measured for different press speeds and tonnages. By damping the impact on the load cells, the shape of the load-time curve was made to better represent that of a real process such as blanking. The results of these tests will help to improve understanding, allowing future press applications to be set up faster and more precisely. The information gained from this study will help to improve the practical utilization of high speed presses by (a) improving instrumentation and monitoring techniques, (b) facilitating rapid and precise tool set-up, and (c) incorporating dynamic considerations in process and tool design.

1. Introduction

Increased demand for small sheet metal parts, particularly in the electronics industry, has motivated press manufacturers around the world to develop high speed blanking presses. These presses are presently capable of reaching speeds up to 2500 strokes per minute (spm) and typically operate with short strokes and relatively low load capacities. The importance of high speed presses is apparent from the wide range of products they produce including such parts as small mechanical and electrical connectors, razor blades, and computer lead frames.

Maintaining close tolerances, along with reliable performance and high productivity, is a significant challenge in the operation of high speed presses. As such, a clear understanding of the variables that affect part quality in a high speed forming process is essential.

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the bolster at the bottom dead center position) over the speed range of the press is a prerequisite for achieving proper tooling setup and desired part quality.

So that the above mentioned performance characteristics may be studied objectively, an experimental setup must be devised which is capable of providing accurate and repeatable data about the performance of a high speed press.

2. Experimental Setup

2.1. The High Speed Forming Press

The investigations discussed in this report were performed on a mechanical high press with a load capacity of 60 tons, a stroke rate of 200 to 1200 spm, and a stroke length of 1 inch. This high speed press, seen in Fig. 1, is equipped with standard features (including a balancing system), which are designed to help compensate for the effects of dynamic loading.

2.2. Simulated Loading

To produce consistent and repeatable loading conditions, Helm calibration load cells were placed on the press bolster so that they could be loaded at various speeds and desired load levels by adjusting the shutheight, Fig. 2. This setup is similar to that used in previous low speed investigations [3]. By moving the load cells along the left-right centerline of the press, both on-center and off-center loading conditions could be simulated.

2.3. Shutheight Measurement

Changes in shutheight and slide parallelism are usually measured by means of analog proximity sensors or laser displacement sensors [4]. In the present study, Indicon analog proximity sensors were used. These inductive proximity sensors were placed in each of the four corners of the bolster and are capable of measuring the position of the slide to within 0.0002". Using this sensor configuration allows the slide-bolster parallelism to be monitored through part or all of the press stroke [5].

2.4. Data Acquisition

All of the sensor signals were processed through appropriate signal conditioners and amplifiers, and then fed to a computer equipped with a National Instruments AT-MIO-16F-5 data acquisition board for processing and analysis. Used in conjunction with the National Instruments LabVIEW software, this DAS (Data Acquisition System) provided a powerful tool for observing and recording the behavior of a high speed press in real time.

3. Experimental Procedure

3.1. Testing Under No-Load Conditions

In the first tests, changes in shutheight and slide deflection were monitored over the whole speed range of the press without applying any (simulated) load. These tests allowed the observation of dynamic effects that are inherent to the press itself.
3.2. Testing Under Simulated Load Conditions

Using the load cells to simulate a forming operation, press behavior was observed under various speed and tonnage combinations. Tests were conducted with and without a damping pad and under on-center and off-center load conditions in order to represent different press operations.

3.3. Repeatability and Reference Values

In order to establish repeatable testing conditions, process variables were always set to nominal values using the same procedure. After allowing the press to reach thermal equilibrium, reference values for the various sensors were established at 200 spm. This means, for example, that changes in shutheight were monitored with respect to the shutheight measured at 200 spm. Likewise, the nominal loads to be studied were also established at a stroke rate of 200 spm.

4. Experimental Results

4.1. Slide Displacement (No-Load)

The position of the slide at Bottom Dead Center (BDC) was monitored over the speed range of the press. The results of these tests can be seen in Fig. 3. A positive displacement indicates that the shutheight is greater than that observed at the reference speed; a negative value indicates a decrease.

The shutheight increases at lower speeds and decreases at higher speeds, Fig. 3. One possible explanation for this behavior is that the equilibrium between the hydrodynamic forces in the journal bearings of the crankshaft and the inertial forces on the slide tends to shift slightly over the operating range of the press.

4.2. Slide Parallelism (No-Load)

Fig. 4 shows the changes in slide tilt over the speed range. A positive value of the displacement per unit length or width indicates a tilt toward the front (front to back) or the right (right to left).

4.3. Changes in Shutheight (Under Load)

Under load, the dynamics of the system become more complicated. The impact of the load cells causes deflections of the slide, crankshaft, frame, and bolster, and influences the balancing system of the press by creating an additional force component. Furthermore, the bearings and guides have to withstand higher forces, affecting the position of the crankshaft with respect to the journal bearings.

Fig. 5 illustrates the variation of press load (originally set to 10 tons at 200 spm) and shutheight with increasing press speed. The shutheight is observed to decrease as the press speed is increased. Presumably, this is due to increased inertial forces on the slide since it must decelerate faster under load. Because the load is both created and measured by the load cells, any change in shutheight must be accompanied by a proportional change in load as is seen here.

Fig. 6 illustrates the variation of press load with increasing press speed. At initial load settings greater than 10 tons, the press load decreases between 300 and 800 spm; at 50 tons, this decrease is nearly 20%. At stroke rates above 800 spm, an increase in effective loading was observed for all initial load settings.
The performance of high speed machinery is primarily determined by the dynamic behavior of elastically deflected linkage components and mechanical components with clearances (such as journal bearings) [6]. Thus, the reasons for this observed behavior can not be explained entirely without a more detailed dynamic analysis of the press.

4.4. Load-Time Curves

The press load data given in Fig. 5 and Fig. 6 refer to measured peak loads. The shape of the load versus time curve, however, provides additional important information. At high press speeds, Fig. 7, the load-time curve shows two distinct peaks; one representing the initial impact of the slide on the load cell, and a second, lower peak, accompanied with oscillations. Since the goal was to simulate a real process such as blanking or coining, which does not exhibit multiple oscillations, the setup had to be modified.

During the initial load measurements, Fig. 7, the load cells were not bolted to the press bolster. One possible explanation that was considered for the multiple peak behavior was that the cells may tend to 'bounce' during testing. However, experiments did not show any significant difference in the load vs. time curves of the bolted and unbolted load cells, Fig. 8.

4.5. Load Measurements with the Damping Pad

In an effort to reduce or eliminate the secondary peaks of the load-time curves, a neoprene pad was mounted between the protection plate and the slide (see also Fig. 2). The results with this setup are shown in Fig. 9. The slopes of these curves seem to better represent the load-time curves obtained in practical press operations. However, the duration of the loading is still longer than in a blanking operation performed at the same speed.

To investigate the effect of the neoprene pad on load measurements, the previous tests were repeated with the pad in place, Fig. 10. The results show that the basic characteristics of the curves remained unchanged. As with all previous loading cases, the load decreased between 300 and 800 spm for all preset tonnages higher than 10 tons. This behavior supports the assumption that the load decrease at lower speeds is press related (bearings, lubrication, balancing system, etc.). The observed load increase at higher press speeds was still observed with the pad, however, the net load increase at maximum speed was lower than without pad, Fig. 11. It is speculated that the load increase, dominant at higher speeds, is caused by the high deceleration of the slide and a resulting higher dynamic component of the load. This explains why the behavior is still observed with the neoprene pad in place, but because
of the decreased rate of deceleration, the net load increase is reduced.

The differences in deceleration time can be quantified by examining the slope of the impact portion of the load-time curve, Fig. 9. A higher impact slope is equivalent to a lower deceleration time. It was observed that the deceleration time with pad was on average around 80% longer than without pad, and was the main cause of differences in load increase at higher speeds.

4.6. Off-Center Loading

The ability of a press to handle eccentric loading is termed "angular stiffness" and is a measure of the effectiveness of the press guidance system [7]. Several methods have been developed for the study of angular stiffness including a test which requires the simultaneous upsetting of two different billets (one lead, and one copper) placed opposite each other within the press window [8].

For the present study, the sensitivity of press performance to off-center loading was tested by shifting the applied load 1" left along the left-right centerline of the press. As shown in Fig. 12, the influence on the load distribution was dramatic. Though the recommended maximum off-center loading moment of 60 in-ton was never exceeded, loading from left to right differed by as much as 15 tons and associated slide deflection was observed. In accordance with previous findings [9], it has been observed that any off-center loading adversely affects press performance and should be avoided whenever possible.

5. Conclusions

This series of experiments has shown that the dynamic behavior of a mechanical high speed
press is affected by many different factors. The complexity of the system and limitations in the ability to control all of the variables complicates attempts to isolate and analyze individual sources of dynamic response.

The changes in shutheight observed under no load condition are specific to the press itself. They may be caused by temperature related changes of the lubricant, the tolerances within the bearings, and different balancing conditions of the slide at different speeds. All these effects have a different presence at different stroke rates and in addition influence each other. This inherent behavior may be completely different for another press.

The tests under loading conditions showed that it is possible to simulate several real processes by means of calibration load cells. By damping the impact on the load cells it was possible to achieve a load-time curve similar to a blanking operation, for example. The changes of the peak load over the speed range of the press are mainly influenced by the press itself and by the dynamic part of the load. The load increase at higher speeds reflects the short deceleration time of the whole mass of all moving parts of the press resulting in higher dynamic forces. This behavior will be seen in all presses running at higher speeds, whereas the load decrease seen between 300 and 800 spm is most likely a function of the dynamics of this particular press.

These results show that investigating the performance of a high speed press under different speed and loading conditions helps to demonstrate and understand the dynamic effects. The complex interaction of these effects may dramatically influence the quality of the parts produced and the requirements placed on a press and tooling. Based on the knowledge gained in these tests, it will be easier to fine-tune future processes performed in the press.

References