Application of Engineering Fundamentals in Manufacture - A Case Study

G. Juri Filatovs & Devdas M. Pai
NSF Center for Advanced Materials & Smart Structures
Department of Mechanical Engineering
NC A&T State University, Greensboro, NC 27411

Abstract
A case study is presented that was developed during a Senior Capstone design course and based on an actual industrial problem. In a manufacturing operation, a materials handling cell did not reliably pick-up single sheets of aluminum. Due to parasitic adhesion, two sheets would be fed into the downstream machines initiating jamming or tool breakage. The system had performed satisfactorily for steel, for which the system had apparently been set-up. Initial discussion with the plant managers and engineers revealed a tolerance of the interruptions and a reluctance to attempt correctives. Analysis of the problem and further discussion revealed a lack of understanding of the basic factors, due to a lack of systematic, fundamental approach. The candidate ideas proposed by the plant personnel were, based on elementary analysis, incorrect, and would have exacerbated the problem. This case study discusses both the technical aspects and the reasons for the failure by the personnel to engage the problem. The problems and circumstances were presented to the students, who then wrote a paper on it detailing their analysis and approach to the problem. Following this, the instructor's solution was presented and a discussion evolved. This discussion resulted in advocating for and illustrating the advantages of a fundamental approach to engineering in a manufacturing-design setting.

I. Introduction

This is a case study used in the Senior Capstone design course in the Department of Mechanical Engineering at NCA&T State University. It originated from consulting work with a local industry by one of us (GJF) and was developed into a case study/project. In addition to its technical aspects, the study presented opportunities for examining and comparing the differences in approaches between students and working engineers and incorporating observations on those differences into the lessons learned.

II. Problem Overview

A metal cabinet manufacturer was experiencing intermittent problems in a materials handling cell. Bales of 4'x 8'x 0.05" aluminum sheets had their top sheet picked-up by vacuum grippers, flexed to drop any adhering second sheet, and transported to a downstream station. Figure 1 shows the configuration of the pick-up mechanism. The flexing cylinders at positions A-B-C-D pushed downward sequentially, while the sheet was raised above the bale. The line ran continuously, frequently unattended, and only stopped for major maintenance or problems.

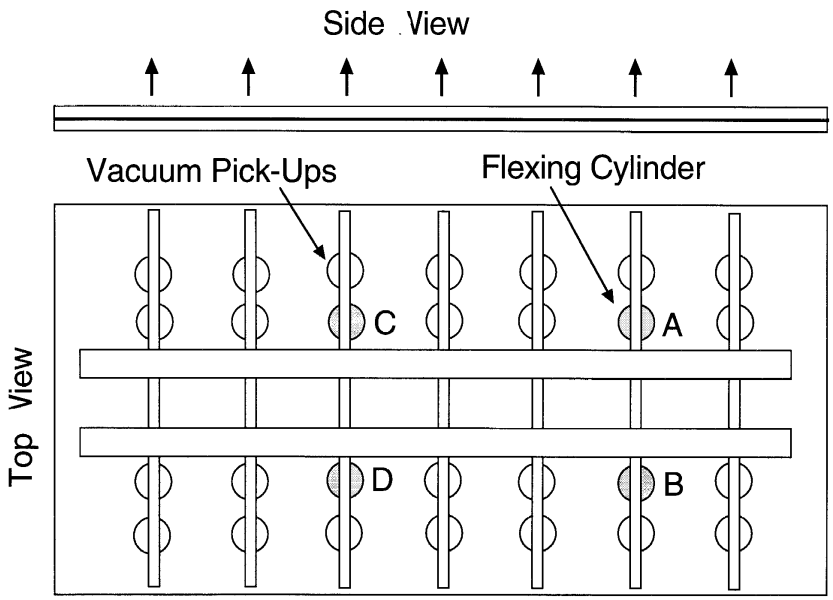

Figure 1 Configuration of Vacuum Gripper Sheet Lifter System

The sheets were coated with a protective oil, which under some conditions caused two sheets to stick and jam the downstream machinery, and resulted in major disruptions. There were detectors for double sheets, but these sometimes failed, and in any case, the line was stopped. The line had operated satisfactorily with steel sheets, and the sticking only occurred with aluminum. The plant personnel concerned with this problem included four BS-level industrial engineers, as well as several technicians.

III. Plant Operators Response

The machinery operated as set-up and programmed by the manufacturer. The pick-up and flexing points could be altered, as could the flexing sequence. The plant operators assumed that the problem originated with the differences in weight between steel and aluminum, but had not contacted the manufacturer, and were hesitant to initiate any changes, as these might require production interruptions more severe than the original problem. They did not appear to have carried out any serious analysis of the problem; the candidate solutions all centered on moving the flexing points closer to the centerline.

IV. Student Project

Initial Approach - The aforementioned facts were presented unembellished to the class, in the descriptive language of the plant personnel, without translation to more technical terms. A preliminary report due in two weeks was assigned. This report showed analysis at about the level of an introductory statics course. Various calculations were made by the students, e.g. the weight of a sheet was 22.35 lb, or 2.79 lb/ft of sheet length. Balancing adhesive and weight forces, and comparison to the steel case, in essence implementing the assumptions of the plant personnel, showed the inadequacy of the analysis and indicated that a more sophisticated model was needed.

More Detailed Model - Following discussion of the preliminary report, a final report, due in two weeks was assigned. Rather than the more obvious and involved computer-based methods, the students were prompted to a more abstract and fundamental approach by suggesting that they browse standard engineering handbooks. This led to a model based on the cantilever beam with a concentrated load at the free end. The pick-up and flexing forces are directly applied only to the top sheet, and are transmitted to the bottom sheet through the layer of oil, which acts as a parasitic adhesive. If the bottom sheet is modeled as a portion of a beam turned upside down, then the curvature imposed on it induces a 'phantom' springback force, acting to straighten or peel the bottom sheet from the top. This is taken to equal the concentrated load. That is, the deflection is forced, and the load which causes the deflection is taken as a concentrated springback force. Figure 2 shows the free-body diagram for this.

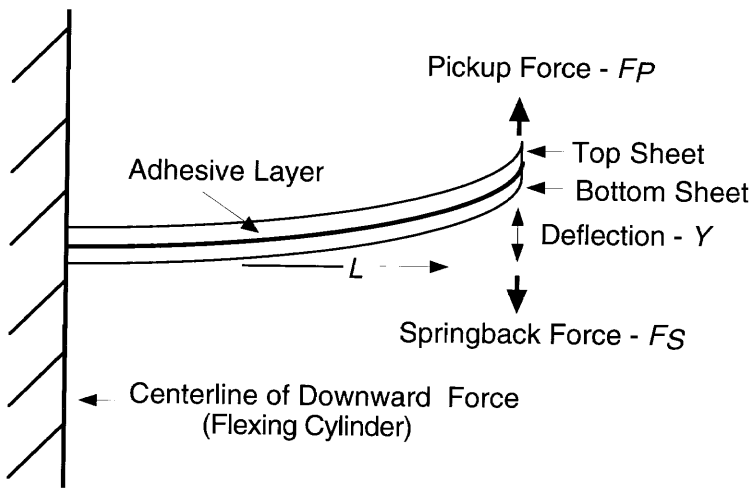

Figure 2 Free body diagram of two sheets adhering together

We sketch the dominant functional dependence. Summing moments about a flexing cylinder at L = 0, with W = distributed weight and F_A the adhesive force, the springback force F_S is

$$F_S * L + W * L * L/2 = F_A * L * L/2 \quad (1)$$

and recalling that the maximum deflection Y of the free end of the beam

$$Y = F_S\, L^3 /NEI, \quad N \in (3, 48,\ldots..) \qquad (2)$$

gives that

$$F_A = f(L^{-4}) + W \qquad (3)$$

suggesting that the closer F_P is to an edge, and the least separation between F_P and F_D, the higher the springback force. Therefore, the cylinders could be rearranged and sequenced, perhaps siamesed, to create the highest springback. This line of reasoning clearly is contrary to the proposals of the plant personnel.

V. Concluding Observations

The plant personnel were reluctant to experiment, even though they were convinced o the line of reasoning. Without invoking sophisticated diagnostic language, it appeared they were content to tolerate the occasional (machine caused) breakdown rather than risk down time and blame if the problem was not solved. The principal failure on the part of the plant personnel was unwillingness or inability to apply, or have faith in, a fundamental engineering approach. They were practicing a notional-type of engineering and relying on equipment manufacturers for technical solutions that should have been within their ambit. This observation was an important one to make to the class, as they were future ex-students, liable to the same kind of slippage in their skills.

This made for a case study within a case study. The original problem as presented to the consultant/instructor was assigned to the class as a design problem, and provided a realistic and interesting technical topic. Collaterally, the approach of the plant personnel was used as a case study in both the process of design and as a lesson on the manner in which problems may not be solved in industry. Students gained an extra dimension from this approach.

The implementation consisted of class discussions and the two previously mentioned reports. A portion of the final report required an audit, including discussion of the plant personnel-response, examining the impact of social and behavioral issues on the practice of engineering. Additionally, the inadequacy of simple analysis was discussed. The students concluded that professional obligations were not met by the avoidance of fundamental analysis, and learned a lesson beyond the technical aspects.

Bibliography

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G. JURI FILATOVS
Juri Filatovs is a Professor of Mechanical Engineering at NC A&T State University. He received his Ph.D. from the University of Missouri-Rolla. He has worked for McDonnell Aircraft and the US Bureau of Mines. His research is in the area of materials and properties of materials. He teaches the introductory materials science and the capstone design courses in mechanical engineering.

DEVDAS M. PAI
Devdas Pai is Associate Professor of Mechanical Engineering at NC A&T State University. He received his M.S. and Ph.D. from Arizona State University. He teaches in the area of manufacturing processes and machine design. A registered Professional Engineer in North Carolina, he serves on the Mechanical PE Exam committee. He is active in the Manufacturing and Materials Divisions of ASEE.