The Robust Optimisation Of A Vehicle Mounted Lifting Mechanism To Combined Weighted Objective Functions.

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Abstract

The performance of a vehicle mounted hydraulic lifting mechanism was to be optimised to give the best lifting characteristic in a specified working envelope. The lifting mechanism had to achieve a minimum lift force as well as providing a desirable lift force characteristic over its full operating range.

The statistical software package MINITAB and 'Design Of Experiments' techniques were employed to explore the performance of the mechanism and find the key parameters affecting its performance. Optimisation of the mechanism was carried out using a number of methods.

By optimising a virtual prototype the mechanism improved it's lifting capacity by up to 50%, although a lift curve with a more desirable shape was achieved with a 28% increase in lift capacity.

The final optimised lift curve used a weighted measure objective function to control the shape of the lift curve. This provided a robust optimisation method throughout different iterations of the mechanical design.

Introduction

The vehicle mounted hydraulic lifting mechanism studied in this paper is typical of those mounted to the rear of off-highway vehicles working in agricultural and forestry environments. It allows the attachment of a variety of implements and tools necessary for everyday work.

Figure 1 shows the mechanism.

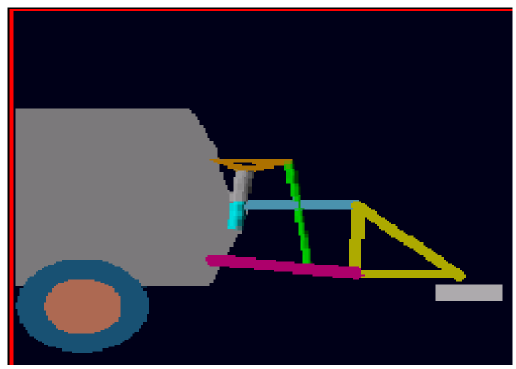

Figure 1 - Lifting Mechanism

Objectives

The objectives of the work were to:

- improve the lifting capacity of the mechanism by at least 25% through geometry changes.
- provide a desirable lift force characteristic over the mechanism's full operating range.
- develop a robust method of optimising the characteristic curve shape.

Modelling

Model Description

ADAMS/View was used to construct a parametric model of the linkage, allowing geometry and tolerances to be described and varied using design variables. The linkage was modelled in two dimensions to reduce complexity.

The ram force was modelled using a Single Component Force element and the lifting capacity determined by displacing the end of the mechanism through the specified operating envelope using a jack and measuring the reaction force at the jack.

Design Variables

Only four geometry points could be moved to improve the performance of the mechanism. These were:

- Lift Arm Pivot (x, y co-ordinates)
- Lift Arm End Pivot (x, y co-ordinates)
- Ram Upper Pivot (x, y co-ordinates)
- Lower/Drop Arm Pivot (x co-ordinate)

Figure 2 shows these points.

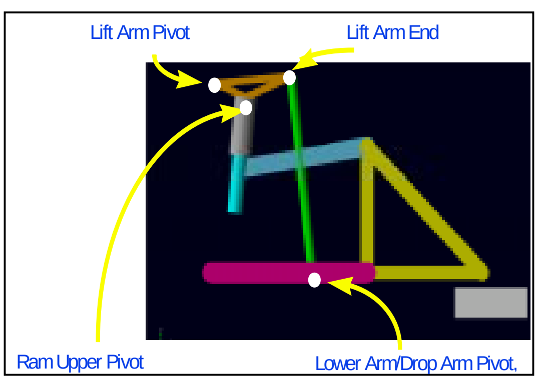

Figure 2 - Design Variables

Definition Of Constraints

The mechanism, although of an industry standard type, was to be fitted to a new product and was subject to a variety of packaging and performance constraints. The ram size and pressure could not be changed.

Packaging and performance constraints were defined using constraint functions, which are used to check that any solutions found during optimisation are within specified boundaries. The constraints defined were:

- the maximum cylinder length.
- the minimum cylinder length.
- the clearance between the Ram Upper Pivot and the Lift Arm End Pivot.

Figure 3 shows the constraints that were to be satisfied.

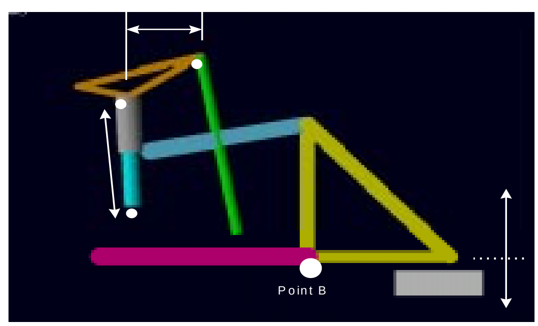

Figure 3 - Model Constraints

What Makes A Good Lift Curve?

The ideal lift curve would be described by a straight line that rose gently in magnitude as the linkage lifted. This is not always possible and the lift curves, as the name suggests, tend to be curvy. The main features of a good lift curve are:

- Peak force to the right of horizontal
- Range minimised
- Small drop off after peak value
- Final force higher than initial force

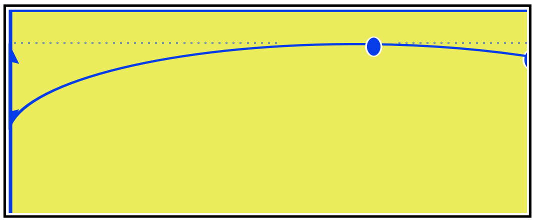

Figure 4 - Ideal Lift Curve

Baseline Results

The baseline lift curve had the right shape, but the minimum force was too low. Figure 5 shows the baseline curve obtained from running the model.

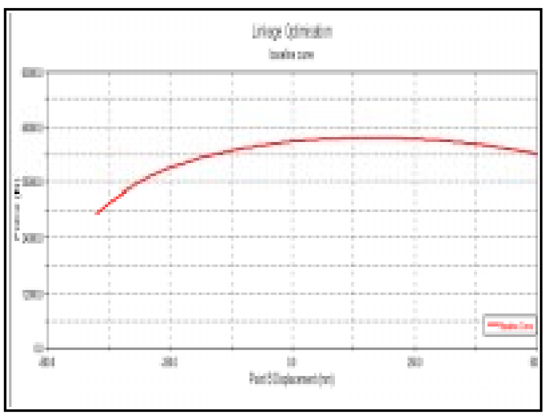

Figure 5 - Baseline Curve

Studying The Model

Design Studies

Single parameter design studies were used to investigate the effects of changing one variable at a time on the lift curve. Figure 6 shows a typical design study, where the Ram Upper Pivot y co-ordinate was varied in its design range and a lift curve obtained.

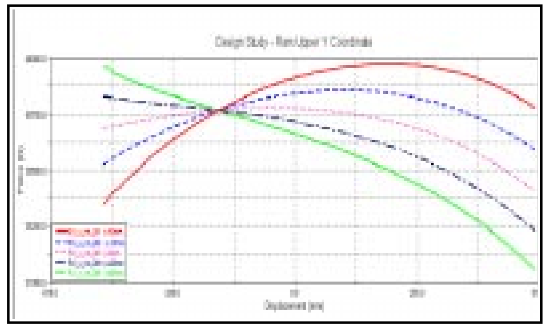

Figure 6 - Ram Upper Pivot Y-co-ordinate Design Study

Design Of Experiments

Design Of Experiments (DOE) techniques were employed to identify the main factors influencing the following parameters:

- Maximum Force
- Minimum Force
- Force Range
- Position of peak force
- Maximum negative gradient

A full factorial experiment was carried out, resulting in 128 runs per experiment. The results from each experiment were then loaded into the statistical package MINITAB to produce mean effects plots , used to highlight the average value of the measure being studied and the effect of each parameter on that measure. Insignificant factors could then be removed from the optimisation process. Figure 7 shows the results of two experiments. It was found that all of the factors should be included as all had a significant effect on at least two of the measures.

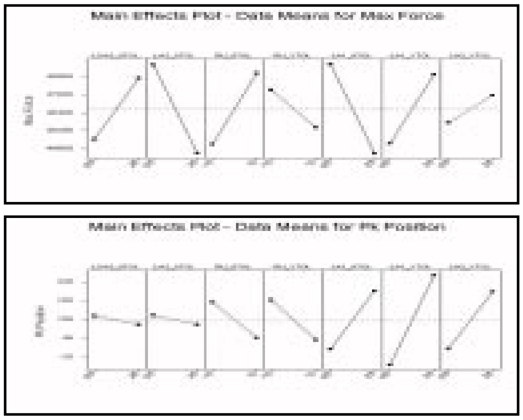

Figure 7 - Main Effects Plots

Basic Optimisation

Basic optimisation functions were used to optimise the maximum, minimum, average or last value of a measure, whilst satisfying the defined constraints. The optimisations carried out were:

- maximise(minimum force measured)
- minimise(force range)
- maximise(peak force position)
- maximise(min negative gradient)

Figure 8 shows the results of the basic optimisation.

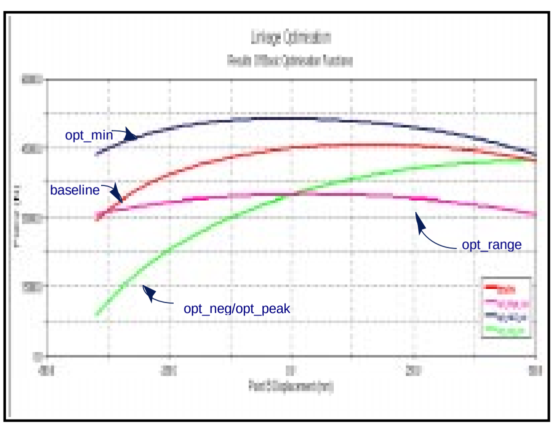

Figure 8 - Results Of Basic Optimisation

The optimisation produced curves that did not satisfy the features of a good lift curve.

Imposing a Lower Force Limit

Two of the optimisation techniques, 'maximise the minimum negative gradient' and 'minimise the range', produced curves with desirable characteristics, although the minimum force was far too low. To improve the lift capacity a minimum force constraint was added to force the minimum lift force to be increased by at least 25%. The optimisations were then re-run. Figure 9 shows the results of the optimisation.

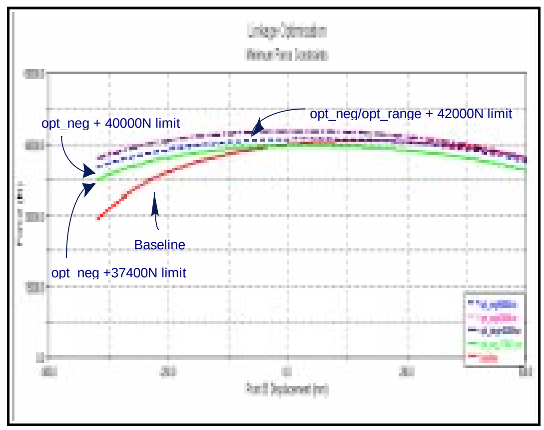

Figure 9 - Imposed Minimum Force Constraint

The curve shown are for 'maximise the minimum negative gradient' with 37400N, 40000N and 42000N minimum force limits and 'minimise the range' with a 42000N force limit. The lift curves produced have an improved range and minimum lift force, but they are quite symmetrical with a peak force occurring close to horizontal and a final force not far above the initial force.

Care must be taken to start the optimisation from a condition where all constraints are satisfied. Specifying a minimum force higher than that being achieved initially can cause the optimisation to fail, and is therefore not robust.

Advanced Optimisation

A variety of techniques were used to control the shape of the lift curve.

Weighting Function

The first technique employed was using a weighting function using the STEP function. Figure 9 shows the technique.

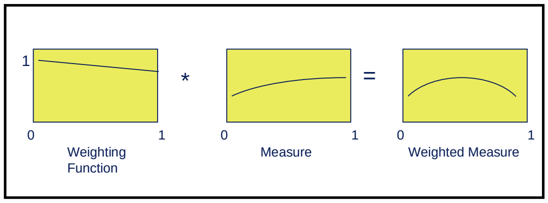

Figure 9 - Weighing Function

The weighting function was used in conjunction with the maximise (minimum force) measure. Without the weighting function the lift curve was symmetrical. The effect of the weighting function is to artificially lower the lift curve measure so that the end is lower than the start. This forces the actual lift curve to be asymmetrical, with the end force being higher than the force at the beginning of the curve.
Figure 10 shows the effect of different weighting functions on lift curves obtained.

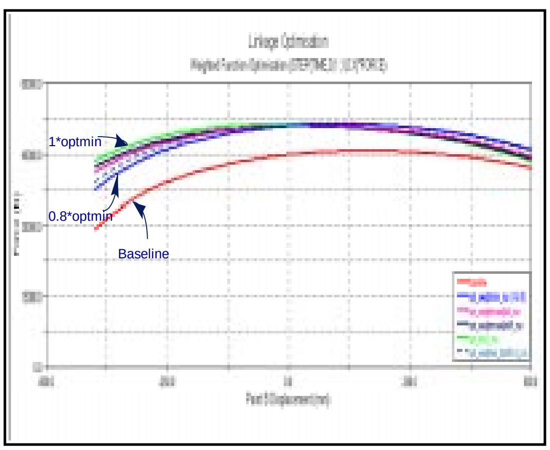

Figure 10 - Weighted Function Results

Fit to a line

Using a ‘fit to a line’ method requires a full understanding of the capability of the linkage before optimisation. It should be noted that you may specify a desired line that cannot be achieved. Two different methods were employed with different levels of success; *fit to a spline* and *control point* methods.

Fit to a spline

A force-displacement characteristic was defined using a spline and the measured force at a point compared to the spline value at the same point and the error measured. The average error value over the full range of the linkage’s movement was then minimised.

The results from the previous optimisations were used to judge what an achievable lift curve would be. The ’best’ curve found by the weighted function method was specified using the spline function. ADAMS managed to reproduce the curve produced by the weighted function method, not surprisingly. The spline was altered to try and increase the last force. An improvement was not achieved, with the constraints imposed. Figure 11 shows the results of the optimisation.

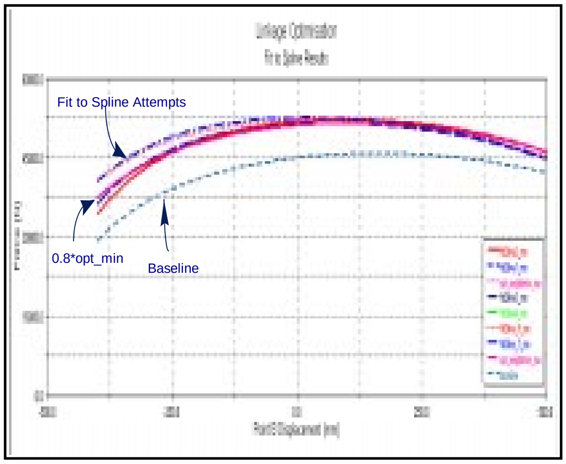

Figure 11 - Fit To A Spline Results

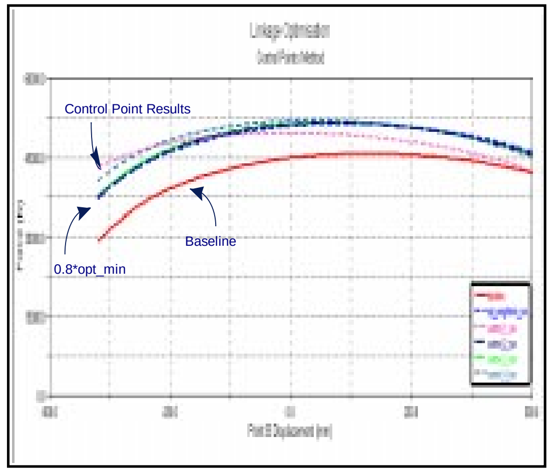

Figure 12 - Control Point Optimisation

This method can provide good results, but can give a lift curve that is a different shape to the desired curve (the final force is lower than the initial force for example), especially if it cannot achieve the desired curve's force level.

This method did not give an improvement over the best curve obtained by the weighted function method.

Control Point Method

This method gives a different way to control the shape of the lift curve. Five key points on the lift curve are defined as ADAMS/View variables, in much the same way as you would when defining a spline. These values and the measured force are passed to an ADAMS user-written subroutine that measures the error at each control point and minimises the error to provide a curve that matches the desired curve.

Figure 12 shows the results of the control point method.

Results of Optimisation

The optimisation work carried out produced a range of lift curves that could be deemed better than the original in one way or another.

Basic Optimisation provided a lift curve that increased the lift capacity by 49%, but that had an undesirable shape. Other curves were better shaped, but did not improve the lift capacity.

Using the weighted function technique provided the capability of controlling the shape of the lift curve and reaching a compromise between increasing the lift capacity and achieving the desired shape.

The 'optimum' curve was a compromise between achieving the desired lift capacity **and** the lift curve features required. The baseline and optimum curves can be seen in Figure 13.

The optimum curve gives the desired shape of curve with a 28% improvement in lift capacity.

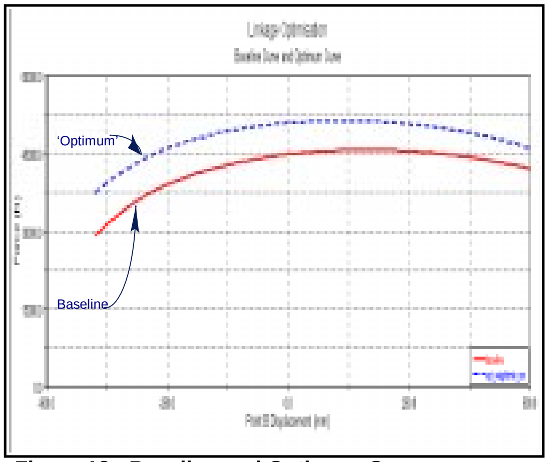

Figure 13 - Baseline and Optimum Curves

'Fit to a line' methods can produce good lift curves if the performance of the mechanism is fully understood. They are more complicated than the weighted function method and offer less control over the lift curve characteristic.

Conclusions

Optimisation is often a *process* that eventually leads to the 'optimum' result, after a period of *investigating* and *understanding* the design and its performance, designing functions to *control* how the system is optimised and *recognising* the solution that gives the best *compromise* between the optimum solutions found using each method.

Methods employed in the optimisation of a vehicle mounted lifting mechanism have been discussed.

The weighted function technique proved to be a simple way of defining a normally 'subjective' approach to lift curve shape design.