Redesign Proposal for Constant Spring Force Pipe Supports

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Abstract

Pipelines used within industrial applications are often subjected to thermal loading due to expansion at joints. This can cause pipework to displace up to several hundred millimetres which is significant enough to induce damaging stress concentrations at suspension points where motion is constrained. Pipe supports are designed to accommodate vertical displacements of pipe and small variations in loads by exerting approximately constant supporting forces, produced by employing combinations of components such as springs, cams, linkages and levers. Currently the industry partner, Binder Group produces a Constant Effort Support range based on the principle of moment balances to implement a counter-balancing arrangement using bell crank levers. This project sought to investigate and develop a new mechanism which alternatively utilises a central pull suspension method and modular design to potentially extend Binder Group's current load and travel ranges, to enable more effective competition and cost benefits. It was ultimately shown that minimal component variability and hence cost reduction could be established across the new range by allowing incremental angular and lever arm length adjustments within the mechanism.

1. Introduction

Pipelines are crucial to the transfer of gases and fluids in the oil and gas, power generation, petrochemicals, mining and mineral processing industries (Binder Group, 2014). Due to the range of applications, pipe-work is often subjected to different kinds of dynamic and static loading conditions. Consideration must therefore be made with regards to accommodating varying loads under operating conditions, particularly in the design of supporting members and suspension systems. Operating loads such as deadweight loads, hydrostatic loads, thermal loads and loading due to thermal expansion at joints (Manufacturers Standardisation Society of the Valves and Fittings Industry Inc., 2009) can cause pipework to displace up to several hundred millimetres (Su et al, 2011). This induces high stresses at suspension points where the motion is constrained, resulting in potentially dangerous fractures. In order to avoid excessive stress at suspension points, vertical supports are designed to accommodate for displacements caused by load variations, by providing a near-constant supporting force (Kohler & Clifton, 1962).

Over the years, manufacturing companies supplying pipe supports to the resources industry have developed various constant force pipe support mechanisms. Many utilise a hanging pull style support like the proposed design and incorporate optimal arrangements of mechanical components like springs, cams, links and levers, achieving an efficient and simplistic design that reduces production costs whilst enhancing commercial viability. The two most common approaches of providing constant suspension force on pipe systems are the lever arm bell crank mechanism and the centralised pull mechanism with main compensated spring. These approaches can be generalised by two mechanical principles; torque balanced and force balanced respectively (Su et al, 2011). Torque balanced spring hangers work on the principle that torques exerted on lever arm components of the device due to a suspended pipe load are balanced with opposing moments provided by a spring force or similar acting on crank components. Force balanced spring hangers are governed by the principle that the constant supporting force on the pipe load is directly provided by springs aligned in certain orientations such that the force vectors sum together to output a constant reaction force.

The international design and manufacturing company Binder Group produce a Constant Effort Support which applies the principle of moment balances to implement a counter-balancing arrangement. A compression spring and bell crank lever work in conjunction to provide constant force against an equivalent pipe load. A standard range of 66 sizes with loads between 15 kg and 31876 kg (0.15 – 312 kN) and travel distances between 40 mm and 410 mm in 10 mm increments are available for order from Binder Group, with custom-designed orders also offered for specific requirements outside the standard range (Binder Group, 2014). The sizes of the Constant Effort Support are dependent on the stiffness of the spring coils and lengths of the lever arms which are selected to accommodate the operating conditions required by a customer. However modifications or adjustments to cater for load and displacement variations within a certain support size are limited which presents an impending problem whereby new pipe supports must be installed to reflect changing conditions over time. In order to cater for all possible operating conditions, Binder Group would be required to manufacture intermediate incremental sizes and combinations which is ultimately an expensive and demanding approach.

The objective of this project was to investigate and develop a proven design strategy which implements a modular, central pull system to provide constant force suspension for pipework. The principle behind the proposed design was mathematically justified through derivations and numerical calculations. A modular design was also investigated which will enable the force provided by a single cell to be multiplied or increased by coupling multiple cells. It must be noted however that design of exterior components such as mountings, housings or aesthetics of the constant support was beyond the scope of this project. In addition, the project aimed to reduce component quantities, with a primary objective of developing a simple enough design to effectively deploy resources and minimise costs.

2. Design Process

Binder Group was interested in implementing a central pull and modular design approach without infringing on their competitors' patented designs. Patents and catalogues from competitors were used to gain familiarity with the past and current approaches as well as establish design boundaries to avoid breaching patent laws. The design principles, load ranges, travel ranges, specialised components such as cams and levers, compensatory methods and adjustment methods were assessed to enable a holistic view of the different approaches. Other approaches used to achieve constant force outside the pipe support application were also explored, such as within automotive applications and a shotgun recoil mechanism. The research provided a stimulus to formulate novel ideas in the following stage which included generating design sketches, mathematical derivations and determining the major variables relevant to the design concept. Quantitative analyses were carried out with reference to quantities from Binder Group's existing catalogue and spring specifications to evaluate the practicality of the force and displacement magnitudes and the effectiveness of the mechanism in generating force constancy. Plots of the force output against travel and spring displacements were generated using Wolfram Mathematica computational software to aid the analysis process. The feasibility of the design depended upon a range of factors such as the whether the range of force and displacement magnitudes were reasonable for the application, the accuracy of the constant force output, the size of the mechanism, the adjustability of the force and travel outputs, and most importantly; the costs associated with necessary materials, components and fabrication processes. Once the validity of the design had been established, further work was done to refine the design by selecting appropriate dimensions and parameters to produce different ranges of force outputs and travel variations necessary to cover Binder Group's existing range and beyond.

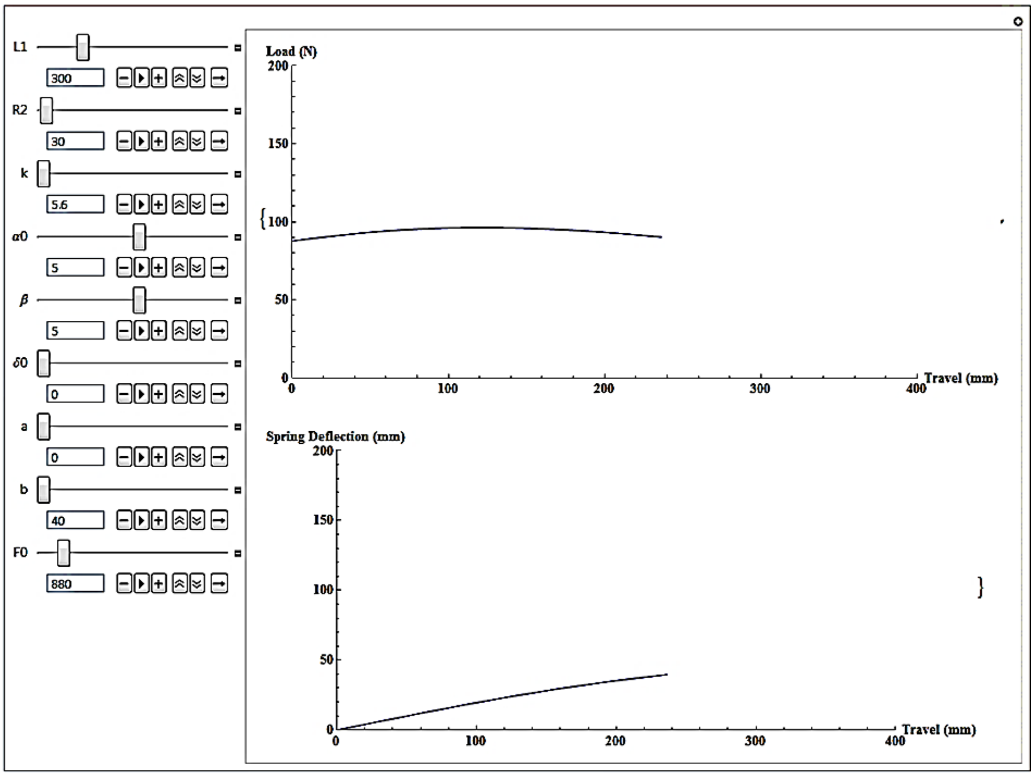

Figure 1 Parametric plots of supported load and spring deflection versus travel distance using Wolfram Mathematica computational software, allowing manual parameter inputs and slider adjustments.

Another computational routine was created within Wolfram Mathematica to plot equivalent load against travel, as functions of the cumulative angular displacements of the lever arm from the initial pre-set position. Adjustable parameter sliders were enabled to visually estimate optimal values which gave sufficiently constant forces for given spring rates. An example can be seen in Figure 1 above for a spring rate of 5.6 N/mm with initial working load of 880 N (Binder Group Procurement & Technical Specification, 2012). The variable parameters, namely effective load arm length L_1, crank arm length R_2, spring rate k, lever arm angular offset α_o, crank arm angular offset β, initial spring compression δ_o, angular travel range $\theta = [a, b]$ and minimum working spring load F_o, come from the design equations for the supported load and travel. Additionally, a plot of spring deflection against travel was created to check that the equivalent spring compression did not exceed the spring range to avoid reaching solid length. Percentage deviations from the mean supporting force were also calculated and tabulated for each angular displacement increment to verify the force was kept relatively constant and within 6% of the mean force, as per the industry standard MSS-SP58-2009. The standard provides guidelines for the materials, design, manufacture, selection, application and installation of pipe hangers and supports (Manufacturers Standardisation Society of the Valves and Fittings Industry Inc., 2009).

After establishing the parameters and dimensions were practical and covered several sizes of Binder Group's current pipe supports, CAD models of the design were generated using SolidWorks Drawings. Three dimensional models enabled the proportions and scale of individual components to be assessed and improvements were made accordingly as the refining process advanced. Angular range was found in particular to affect the overall height of the mechanism as well as the requirement of a longer lever arm making it proportionally large relative to other components. As a result, further fine-tuning was done through the Mathematica routine until optimal dimensions and parameters were established. Finally, design tables showing the supporting forces and travel variations for each individual pipe support size were produced and corresponding CAD drawings for selective sizes within the small, medium and large ranges of pipe supports were generated.

3. Final Design

The final design works on a similar principle to the lever arm bell crank method curently implemented by Binder Group. However the lever arms face inwards on either side of the springs and symmetrically meet at the centre to enable a centralised pull design, as shown in Figure 2 below. The pipe load is supported by a bracket which is mounted on guide rollers resting between the intersections of each pair of lever arms either side of and adjacent to the spring length. By symmetry, the left and right sides of the mechanism must have the same moment balance equations. A load of half the total load P is taken by each side and acts perpendicularly upon a constant effective lever length L_1, i.e. the distance between one pivot and the centre of the mechanism. This is balanced by the restoring spring force F acting perpendicular to the effective crank arm of length L_2. Due to the commericial in-confidence nature of this project, the design equations and optimal parameters will be omitted from this paper.

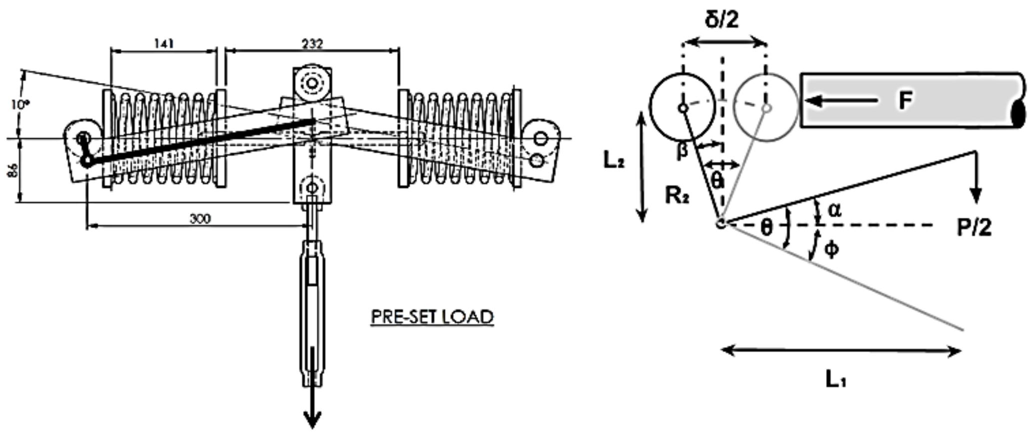

Figure 2 CAD model of proposed design (left) and free body diagram (right) illustrating the working principle of proposed design.

To accommodate loads required by clients, the spring pre-compression δ_o can be independently adjusted to increase the supporting force, by pushing the two inner spring retaining plates further apart. This may be done by having a threaded rod connecting the two retaining plates with opposing threads on either end so that turning in certain directions will bring the plates either closer together or further apart. A pin handle through the rod or a flat section may be incorporated to ease the turning adjustment. The flat modular design additionally allows loads to be increased by coupling single cells to form double, triple or quadruple units. The units may be from different size ranges however the travel ranges must match for the coupled units to synchronise during operation. No restriction to the maximum angular travel is necessary since the travel will be dictated by the displacement of the suspended pipe; however safety travel stops may be put in place.

The range of supports produced were grouped into small, medium and large sizes, within which were only slight variations in component size, with the main change between each support size being due to differences in spring sizes. The small support range covered loads from a minimum of 0.12 kN and up to 7.72 kN when coupled, with travel variations up to 226 mm and errors kept well below the required 6% (Manufacturers Standardisation Society of the Valves and Fittings Industry Inc., 2009). The medium range spanned loads from 1.21 kN to 53.6 kN with up to 452 mm travel and the large range spanned loads from 6.57 kN to 330.4 kN with maximum travel of 491 mm. Therefore Binder Group's existing load range of 0.15 to 312 kN with travels from 40 mm to 410 mm has been exceeded by the proposed design range. In addition, the proposed design uses only 15 variations in spring sizes compared to Binder Group's 66 spring sizes which has significant cost benefits.

4. Conclusions and Future Work

The final design was able to achieve constant forces considerably below the allowable percentage error of 6% as recommended by industry standards, however selection of optimal and practical parameters was crucial (Manufacturers Standardisation Society of the Valves and Fittings Industry Inc., 2009).. By seeking a new approach, the appeal of this product to clients may be enhanced, facilitating wider application and enabling opportunities to enter new market sectors. Reducing the variation of spring sizes and the need for unique components over the whole range also means that stocks can be simplified and hence costs per unit associated with manufacturing and ordering components can be minimised. Implementing a modular design additionally enables more flexibility in selection of support sizes for customers and allows sales of more units for larger loads and travel requirements, to Binder Group's benefit.

Beyond the completion of the project, the casing and auxiliary components such as guide slits, travel scales, turnbuckles, pre-set pins and toothed plates or other locking mechanisms to fix the springs during transportation will also need to be designed in accordance to the industry standard MSS-SP-58 (2009). Appropriate housing must also be designed to protect the internal components from sand or grit which may cause wear and reduce the lifetime of the springs (Manufacturers Standardisation Society of the Valves and Fittings Industry Inc., 2009). Stress or structural analysis of the design may be simulated through Binder Group's available FEA software SolidWorks Simulation to further refine the structural stability of components and optimise material costs within the design. Physical testing of a pipe support prototype is usually carried out firstly on Adjustment of travel and loads in the proposed design were independent of each other thus more versatility can be achieved within a single support an unloaded mechanism without spring forces to test the strength of the casing and exterior components. This is followed by dynamic testing with a loaded spring on a rig using load cells to generate plots of the load against travel, to practically validate the accuracy. Further work extending beyond this project may be in developing an Excel tool or similar for determining support sizes for given specifications to ease the selection process for clients. Additionally, different orientations and configurations of the chosen design may be explored for push-style applications and installation in confined space, by implementing vertical springs similar to Binder Group's current Constant Effort range.

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