Jig and fixture design

Profession

ASSIGN BUSTER

Abstract

This paper proposes a design of jigs and fixtures for the mass production manufacturing of Sportsman Race Series aluminum slipper pistons (Probe Industries) that are used in the Chevrolet LS Series V8 engines. The designs of two sets of jig and fixture designs are proposed. The first set (two vee-blocks and a drill bushing) is designed for the process of drilling the wrist pin holes in the piston. The second design (two vee-blocks and a pin locator) is used in the milling of the skirts and lower form of the piston.

The designs use principles of manufacturing facilities design, research on manufacturing practices and 3D modeling software (Catia) in order to optimize quality (accuracy), costs and productivity in the manufacture of such pistons.

Introduction

The Piston

An important mechanical component of an internal combustion engine, the piston is basically a solid part in an airtight cylinder that moves under the pressure of a fluid and transfers the force of the expanding gas to a crankshaft through a connecting rod (The American Heritage, 2005). Pistons typically consist of a few main features.

Pistons are cylindrical. The top part of the piston that comes into contact with the expanding gas is the crown. All pistons have a wrist pin hole to contain a steel wrist pin that attaches the piston to a rod that is connected to the crankshaft. The skirt of the piston is the end opposite the crown and is often milled in the sides to reduce weight.

Selected Component (Chevrolet LS Series V8 Piston)

The specific component chosen for the design project is the Sportsman Race Series aluminum slipper piston (Probe Industries) used in the Chevrolet LS Series V8 engine.

The high-speed nature of a V8 engine requires pistons to have reduced weight to improve engine balancing. Unlike older pistons that were made with cast iron, this piston is made with forged aluminum alloy to reduce its weight as well as improve fatigue life. Furthermore, this specific piston is a slipper piston with a length of only half its diameter and has some parts milled off in order to reduce size and weight dramatically.

Objectives, Scope, and Assumptions

The aim of this design project is to design jigs and fixtures for the mass production of the aluminum slipper piston used in the Chevrolet LS Series V8 engine.

The scope of the design project is limited to designing jigs and fixtures for the only two processes in the manufacture of such pistons that require jigs and fixtures, specifically the drilling of the wrist pin holes and the milling of the skirts and lower form of the piston. The design project does not account for the exact design, accuracy or efficiency of the drilling and milling machines. The strength and hardness of the materials are not considered. The time and motion in between the processes are not measured for optimization.

Manufacturing the Component

Component Design

The exact specifications and design of the piston for the Chevrolet LS Series V8 engine were taken from a manufacturer of such pistons, Probe Industries. The bore (diameter) of the piston is 4 inches and the height is 2 inches. The wrist pin hole is 0. 927 inches in diameter and centered at 1. 155 inches below the crown. The wrist pin length is 2. 5 inches, meaning that the skirt below the oil grooves is milled at each end of the wrist pin hole up to 1. 25 inches away from the center of the cylinder (Probe Industries, 2012). These dimensions are important in the milling and drilling processes in the manufacture of the piston.

The image below shows the rest of the dimensions and the tolerances (calculations shown later).

Machining Processes in Manufacture of Component

After forging a solid aluminum slug into the basic shape of the piston with the desired strength and stability, the component undergoes several machining processes. The first machining process involves using a lathe or a CNC turning machine to make the base, cut out oil rings or grooves, and drill oil holes. The second process is to drill a large hole on one side of the piston through to the other. This (wrist pin hole) is where the wrist pin is placed to attach the piston to the connecting rod.

The third process is to use a milling machine to shave off material at the sides where the wrist pin hole was drilled in order to reduce the weight of the piston. The fourth machining process involves finishing with a lathe machine, wherein the crown is made into its final shape, the bottom edges of the skirt are shaped, and slots/engravings are made.

Machining Processes Requiring Jigs and Fixtures

The only processes that require jigs and fixtures are the second and third machining processes, the drilling process and milling process. The first and the fourth process use CNC turning/lathe machines and they require no jigs or fixtures.

The process of drilling the wrist pin hole however requires a bushing to locate the point in the cylinder that needs to be drilled as well as a lower vee-block (with a locator at on end) and an upper vee-block (with the bushing and a pin/screw connecting to the lower vee-block) to hold the cylinder. The process of milling requires a lower vee-block as well but with a pin that goes through the wrist pin hole to hold the piston in place in the vee-block. A second, upper vee-block is used to guide the milling machine. The upper and the lower vee-block are referenced to each other with pins.

Functional Analysis of Jigs and Fixtures

Drilling Process

For the drilling process, a vee-block fixture is required to hold and support the cylindrical component. The design of the vee-block includes a locator at the end of the cylinder to keep the piece from moving and to help put the cylinder/piston in the right position. To drill the hole, a bushing is required to guide the drilling machine. The bushing goes through an upside-down vee-block that is put in location by pins connecting it to the lower vee-block.

Milling Process

For the milling process, the piston must be held in the right position and orientation. A vee-block is again used to support the cylindrical piston. And a locating pin is placed in the center of the vee-block at an exact location along it in order to put the piston in the right position along the vee-block and at the right orientation (hole facing upwards) for the milling to be correct (since only the sides with the holes must be milled and only exactly below the oil rings).

A thin upside-down vee-block is strapped on to the top of the cylinder and connected to the lower vee-block at an exact location (using pins or screws) in order to hold the piston in place and to keep the milling machine from milling into the oil rings. To mill the other side, the piston is simply turned over and fitted into the locator from the newly milled side.

Tolerance Calculation

Tolerance Calculation of Jig and Fixture for Drilling Process

To compute or the tolerance of the upper jig of the drilling process, the tolerances of the left and right locating pins and pin holes are computed first. The tolerances and the clearances must be just enough so that both locating pins can fit in the pin holes (in all cases including largest and smallest size of one or both pins and of one or both holes). It should be noted that the worst possible scenario is that on one side of the jig, the hole is the maximum size and the pin is the minimum size while on the other side, the hole is the minimum size and the pin is the maximum size. Given that the diameter of each pin hole in the jig is 12. mm (or 0. 5 inches); the tolerance chosen for this is plus/minus 0. 01 mm (leading to a range of 12. 69-12. 71 mm for the diameter of the hole). A clearance of 0. 05 mm is chosen, causing the largest diameter for the locating pin to be 12. 64 mm. The tolerance chosen for the locating pin is plus/minus 0. 005 mm (leading to a range of 12. 635-12. 645 mm for the diameter of the pin). In the worst case scenario, on one side, the maximum hole size would be 12. 71 mm while the minimum pin size would be 12. 635 mm (leading to a potential gap of 0. 075 mm and a left or right shift of 0. 0375 mm).

In the worst case scenario for locating pins where one side has a maximum hole of 12. 71 mm and a minimum pin of 12. 635 mm and the other side of the jig has a minimum hole of 12. 69 mm and a maximum pin of 12. 645 mm, the maximum shift of 0. 0375 mm on either side would still allow the larger pin to fit in the smaller hole since there would still be a gap of 0. 0075 mm (12. 69 – 0. 0375 – 12. 645 = 0. 0075). Since the bushing is screwed on tight into the jig, there is no clearance between the bushing and the jig and thus no need to differentiate between the two pieces in terms of tolerance.

The tolerances of the pins and pin holes would cause variation in the position of the drill. The worst case scenario would be if on any side, the pin hole is of maximum size (12. 71 mm) and the locating pin is of minimum diameter (12. 635 mm) leading to a potential gap of 0. 075 mm and a left or right shift of 0. 0375 mm. This shift would cause the drill (center of bushing hole) to move 0. 0375 mm in any direction from the center of the jig, and thus the final wrist pin hole would be plus/minus 0. 0375 mm from the center of the final product (50. 7625 - 50. 8375 mm from the side of the piston and 29. 025 - 29. 3775 mm from the top of the piston). This is within the product specification wherein the tolerance is plus/minus 0. 05 mm (50. 75 - 50. 85

mm from the side of the piston and 29. 29 - 29. 39 mm from the top of the piston). The positions of the locating pins and pin holes for the upper and lower vee-block have a tolerance of 0. 005 mm on any direction and thus cause the position of the drilled hole to be between 29. 335-29. 345 mm from the top of the piston and between 50. 795-50. 805 mm from the side of the piston (still within product specifications).

The locator on the lower fixture as well as the back plate each has a tolerance of 0. 005 mm combining into a worst case shift of 0. 01 mm and would cause the position of the drill to be between 29. 33-29. 35 mm from the top of the piston (still within product specifications). All the other tolerances of the drilling assembly have no effect. 4. 2 Tolerance Calculation of Jig and Fixture for Milling Process For the milling process, the holes in the upper and lower vee-blocks for the pins that locate the upper vee-block are exactly the same as in the upper jig for the drilling process.

Thus the tolerances are the same (0. 01 mm hole tolerance, 0. 05 mm clearance, and 0. 005 mm locating pin tolerance) and so is the worst case scenario (shift of 0. 0375 mm). Since the upper vee-block guides the milling machine with a feeler gauge of 0. 01 mm, the worst case scenario would mean that the milled section is either 0. 0375 mm too high or too low on the piston (16. 7625 - 16. 8375 mm from the top of the piston). This is within the product specification wherein the tolerance is plus/minus 0. 05 mm (16. 75 - 16. 85 mm from the top of the piston).

As of the lower fixture for the milling process, the symmetrical vee-block allows the cylindrical component to remain centered without rolling even when the size of the component or the fixture varies, thus eliminating the need to set tolerances. However, the tolerance must be calculated for the locating pin that goes through the wrist pin hole since a gap here would cause milling area to move up or down from the top of the piston. The hole that was previously drilled with a diameter of 23. 55 mm is assumed to have a tolerance of 0. 01 mm from the drilling process.

A clearance of 0. 05 mm is chosen. And the locating pin has a tolerance of 0. 005 mm, thus ranging in size from 23. 49 - 23. 5 mm. In the worst case scenario of a hole with a maximum of 23. 56 mm and a locating pin with a minimum of 23. 49 mm, the potential gap would be 0. 07 mm or a shift of 0. 035 mm up or down the cylinder. This would lead the milling machine to start milling at a point between 16. 765 – 16. 835 mm from the top of the piston. This is within product specification wherein the tolerance is plus/minus 0. 05 mm (16. 75 - 16. 85 mm from the top of the piston).

The locations of all the holes and locating pins should have a tolerance of 0. 005 on any direction in order to keep within product specifications.

Clamp Selection and Force Calculation

For the drilling process, strap clamps are applied on the fixture by using a pair of socket head cap screws on the two sides of the upside-down vee-block. The two socket head cap screws locate the upper vee-block and clamp it to the lower vee-block when holding the work piece piston in place. The diameter of the holes on lower vee-block for screw is 12. 7 mm, thus M12 size socket head cap screws are selected for clamping.

The tool force direction of drilling is downward and it has a tool rotation. The strap clamps fasten the upside-down vee-block and the lower vee-block preventing the cylinder from rotational motion and horizontal motion. The tool force can be taken advantage of clamping down the work piece cylinder. According to Spaenaur (2012), the tightening torque of a screw is the product of torque-friction coefficient, nominal screw diameter, and clamping load (T = KDP). The Table 1 has shown that the M12 socket head cap screw has a minimum tensile strength of 160000 pound per inch, and its material is High Carbon Quenched Tempered.

In addition, it has a production torque of 125 pound. feet. For the milling process, the strap clamps are applied by a pair of socket set screws on the two sides of the thin upside-down vee-block. The two socket set screws locate the upper vee-block and clamp it to the lower vee-block when holding the work piece piston in place. The diameter of the holes on lower vee-block for screw is 12. 7 mm, thus M12 size socket set screws are selected for clamping.

The table 1 has shown that M12 socket set screw has a minimum tensile strength of 212000 pound per inch, and its material is also High Carbon Quenched Tempered. It has a production torque of 43 pound. feet. It can be seen in the related table, the clamping force is approximately 4286 pound. For a drilling machine, Pirtini and Lazoglu (2005) has proved that the pressure over the work piece as the cutter moving down into the work piece with same federate remains a constant value, and additional tests have been suggested that the constant pressure P(f) (MPa) can be described as a function of feed rate (f) (mm/min).

P (f) = 1. 5364f - 103. 06. If the feed rate of the drilling machine is 198 mm/min, then the pressure is 201. 14 MPa. The equation to calculating cutting force is F= P * A. where F is the net force between the measured force and predicted thrust force due to cutting in the thrust direction and A is the contacting area of the cutter at an instant. The force is about 87 kN with the 23. 55 mm diameter drilling hole. For milling machine, we take the piston as an example: Width of cut = 79. 3mm = 3. 122 inch Depth of cut = 19 mm = 0. 748 inch Feed rate = 19. 5 inch/min K" factor = 1. 56 MRR = depth of cut x width of cut x feed rate MRR = 3. 122 x 0. 748 x 19. 5 = 45. 54 inch? /min A formula for calculating horsepower (HPC) of the milling cutter is HPC = MRR/K HPC = 45. 54 / 1. 56 = 29. 19 hp The formulas above are from the article ' A New Milling 101: Milling Forces and Formulas' (Brian Hamil, 2011). One metric horsepower can be defined as the power to raise a mass of 75 kilograms against the earth's gravitational force over a distance of one meter in one second. It can be calculated that the tool force is about 21 kN.

Thus the total cost for our design is approximately 83. 24 AUD. It should be noted that the selling price of the final product ranges between 100-200 AUD.

Conclusion

It can thus be concluded that in the manufacture of Sportsman Race Series aluminum slipper pistons (Probe Industries) for Chevrolet LS Series V8 engines, jig and fixture assemblies can be used for the two machining processes (drilling the wrist pin hole and milling the bottom form of the piston).

The jigs and fixtures designed were basically assemblies of Vee-Blocks with a bushing for the drilling process and another assembly with a locating pin through the wrist pin hole for the milling process. The tolerances were designed in order to not exceed the tolerances in the product specifications. The clamp forces were found to be sufficient and the cost of the jig and fixture is very small compared to the profit made from the final product. The design furthermore is very simple and is thus easily modified to be integrated in a fast-moving assembly line. Therefore it can be concluded that the jig and fixture designs are appropriate.

References

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3. Spaenaur (2012) ' Suggested Tightening Torque1 Values to Produce Corresponding Bolt Clamping Loads'. http://www. spaenaur. com/pdf/sectionD/D48. pdf 9. Appendix Table 1 http://www. torqwrench. com/Info/fasteners. php Table 2 http://www. torqwrench. com/Info/fasteners. php