High Velocity Coolant Delivery System

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Abstract

This paper is for the design and implementation of a high pressure coolant delivery system that will aid in making a step drill grinding process more efficient. Work related and pertinent to a grinding process is used to produce the pilot section of a step drill.

Step drills are used to create highly accurate holes in aircraft skins and stringers. These holes are for the fasteners that hold the aircraft skin to the stringers or ribbing. The step and double margin configuration allows for the drilling of close tolerance holes with hand drilling equipment. The step section acts as a center-drill and stabilizes the tool for the entry of the larger drill body into the hole. The transition angle from the pilot diameter to the main body diameter acts as a secondary cutting lip. The main body has a double margin configuration, which yields contact at four opposite points in the hole. The four contact points improve hole eccentricity as well as minimize hole size variation.

The step grinding process uses a seven-inch diameter resin bonded CBN (Cubic Boron Nitride) grinding wheel. The wheel speed on this machine is seven thousand revolutions per minute. This rotational speed at the wheel periphery translates into thirteen thousand surface feet per minute. This velocity generates an envelope of air around the wheel that deflects flood oil coolant away from the point of work. This oil coolant has great lubricity characteristics, but is poor for dissipating heat. An aggressive feed rate generates enough heat to breakdown the CBN wheel bond, glazing over the wheel, thereby reducing the effectiveness of the wheel. The area of the wheel greatly affected this bond breakdown is the point of transition between the two wheel faces that create the pilot diameter and the transition angle.

The most critical section of the part, with respect to wheel wear is the customer-specified radius at the juncture of the pilot with the transition angle. The lack of coolant at the point of work is only one parameter that can effect this grinding equation. Other parameters that can be adjusted are the wheel diameter, wheel speed, wheel composition, and workpiece-wheel speed ratio. Improvements in these other parameters will generate even more heat at the point of work, making the coolant delivery system even more critical.

1. Introduction

To design and implement a high-pressure coolant delivery system is more efficient to aid in making a step drill grinding process. To produce the pilot section of a step drill is work related and pertinent to a grinding process. In aircraft skins and stringers, step drills are used to create highly accurate holes that are for the fasteners or rivets that hold the aircraft skin to the stringers or ribbing, see Figure 1.

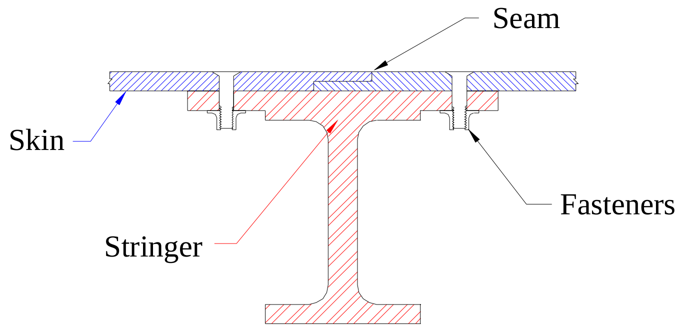

Figure 1: Aircraft Skin Assembly, Fasteners with Stringer.

The step drill being manufactured has a double margin and is 6 inches long with or without a quick change adapter. Figure 2 shows the step drill with a quick change adapter.

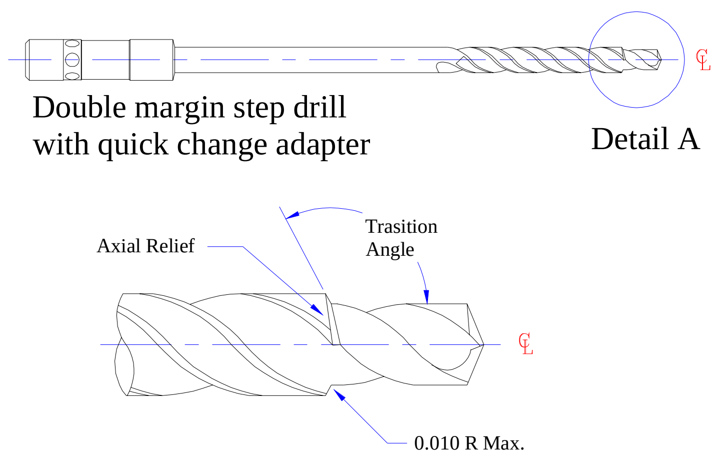

Figure 2: Typical Aircraft Drill, for Pre-drilling Fastener Holes.

The step and double margin configuration allows for the drilling of close tolerance, ±0.002 in., holes with hand drilling equipment. The step section, 0.250 in. long, acts as a center-drill and stabilizes the tool for the entry of the larger drill body into the hole. The transition angle from the pilot diameter to the main body diameter acts as a secondary cutting lip. The main body has a double margin configuration that center of land removed for clearance, which yields contact at four opposite points in the hole. The four contact points improve hole eccentricity as well as minimize hole size variation.

The main production capacity constraint for step drill product stream is a Normac SD50 Step Grinder. Presently 90% of the capacity of this process at present production rate, is sold, or reserved for the next 12 months. There is roughly a 6-8 month lead-time for the purchase and implementation of new equipment. Therefore, it is imperative to generate as much production possible out of existing equipment. Figure 3 shows the step grinding process, which uses a seven-inch diameter resin bonded CBN, Cubic Boron Nitride, grinding wheel.

The wheel speed on this machine is seven thousand revolutions per minute. This rotational speed at the wheel periphery translates into 13,000 surface feet per minute.

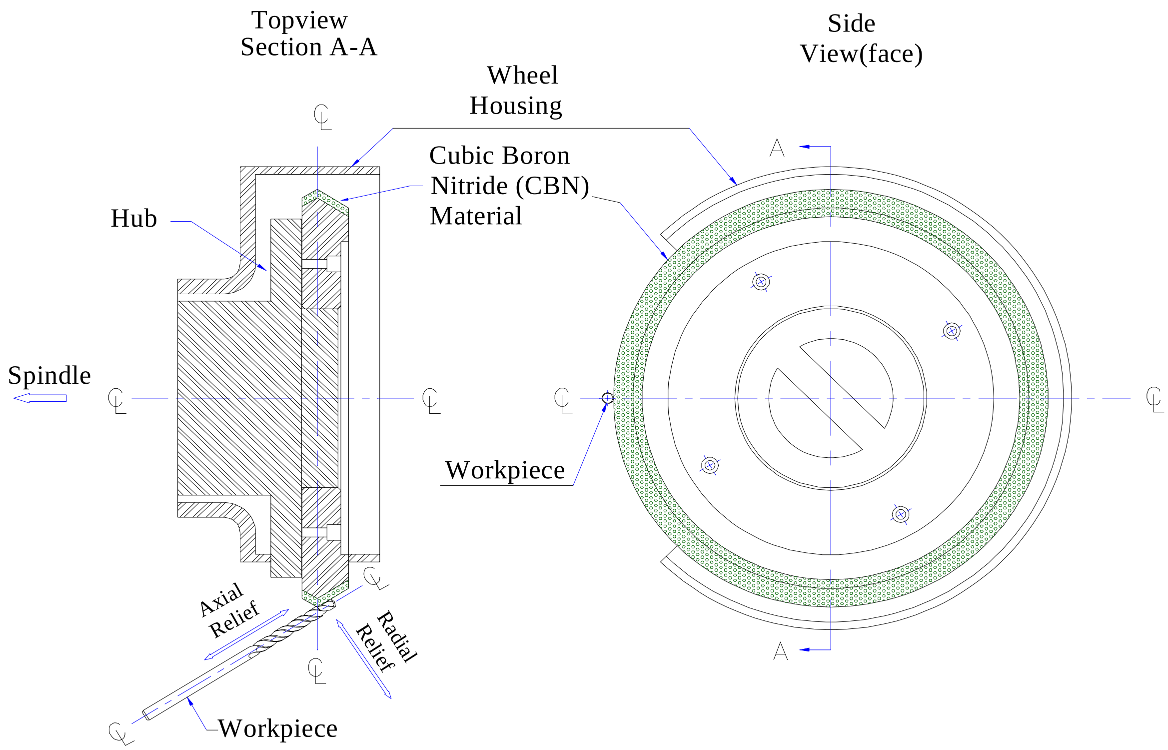

Figure 3: Workpiece and Wheel Configuration - Pilot Grinding Process for Step Drills

This velocity generates an envelope of air around the wheel that deflects flood oil coolant away from the point of work, see Figure 4.

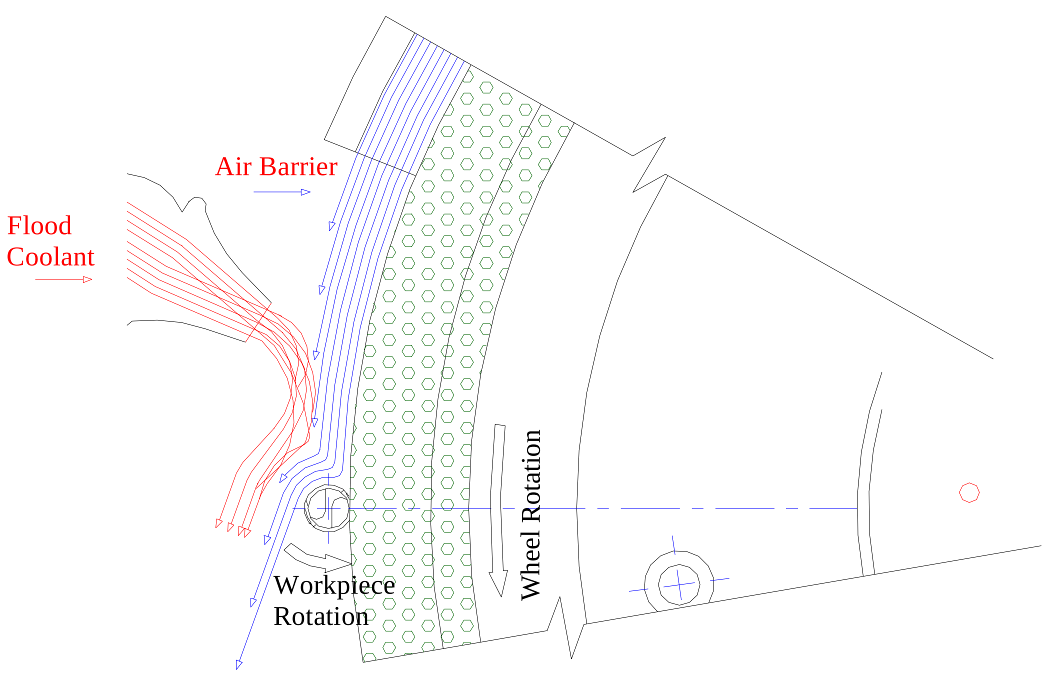

Figure 4: Illustration of Process with Flood Coolant

This oil coolant has great lubricity characteristics [1], but is poor for dissipating heat. An aggressive feed rate generates enough heat to breakdown the CBN wheel bond, glazing over the wheel, thereby reducing the effectiveness of the wheel. The area of the wheel greatly affected this bond breakdown is the point of transition between the two wheel faces that create the pilot diameter and the transition angle.

The most critical section of the part, with respect to wheel wear, is the customer-specified radius at the juncture of the pilot with the transition angle. This radius is usually 0.010 inches maximum. At the present production rates, 120 pieces per hour, the wheel will last for 4,000 parts before the radius degenerates to 0.010 inches. A slightly higher production rate, 130 pieces per hour, reduces the number of parts per truing to well below a thousand. The lack of coolant at the point of work is only one parameter that can effect this grinding equation. Other parameters that can be adjusted are the wheel diameter, wheel speed, wheel composition, and workpiece-wheel speed ratio. Improvements in these other parameters will generate even more heat at the point of work, making the coolant delivery system even more critical [2 & 3].

GE conducted a study to determine the effects of high-pressure fluid delivery and placement [4]. The test analyzed the effect coolant delivery at different pressures from different locations, see Figure 5.

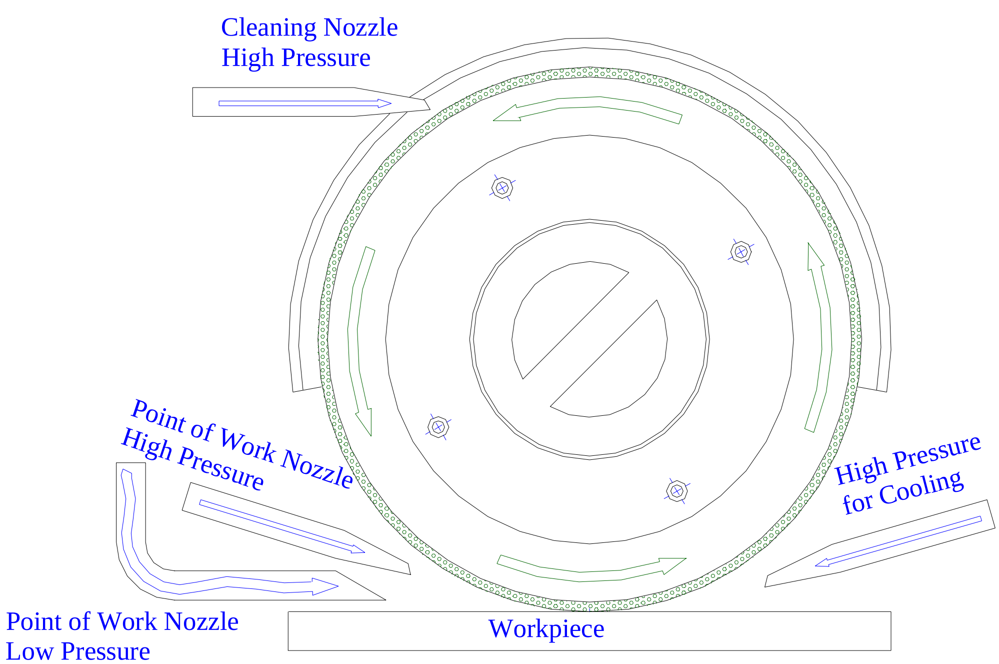

Figure 5: High Pressure Coolant System - Test Configuration

Condition 1: Low-Pressure Point Of Work front nozzle only.
Condition 2: Low-Pressure Point Of Work front nozzle with High-Pressure Cleaning nozzle.
Condition 3: Low-Pressure Point Of Work front nozzle with High-Pressure Cooling nozzle.

Condition 4: Low-Pressure Point Of Work front nozzle with High-Pressure Cleaning nozzle and High-Pressure cooling nozzle.
Condition 5: High-Pressure Point Of Work front nozzle only
Condition 6: High-Pressure Point Of Work front nozzle with High-Pressure Cleaning nozzle and High-Pressure cooling nozzle

The high-pressure coolant was delivered at 300 - 1,000 psi.

The results of this study indicate that when the standard delivery system was augmented with high pressure cleaning, high pressure cooling or a combination of these, grinding performance improved. Further improvements were seen when the standard, low-pressure nozzle was replaced with a high pressure one. Not only did wheel wear decrease, but grinding energy decreased and surface finish improved. With the conventional fluid delivery system only, workpiece burn developed and the test was terminated. In all cases where high-pressure fluid was utilized, no workpiece burn was noticed. A correlation can also be drawn between wheel wear, power requirements and surface finish of the workpiece and the number of high-pressure nozzles being utilized [5]. The step grinding process is essentially a creep-feed grinding process, and should respond analogously to the GE test. The project therefore will be loosely patterned after this test.

2. Methodology

The requirement of the coolant delivery system is to supply a flow of coolant at a velocity equal to or greater than the velocity of the wheel. The design process will require the calculation of the pressure, the flow rate, and the velocity required to match the speed of the coolant with the wheel speed. Equalizing the coolant and wheel velocities will keep the coolant from being “thrown” from the face of the wheel as it is rotating, as well as overcoming the air envelope generated by the wheel velocity [6]. The proper design of the coolant delivery nozzle will generate this high velocity flow of coolant [7]. A detailed financial analysis of the project’s impact will also be included, as it is the prime motivating factor for this undertaking.

The design process sequence is as follows:

i) Define / Select coolant supply system.
ii) Define grinding wheel (target) velocity.
iii) Define pre-design coolant velocity & flow conditions.
iv) Define pre-design maximum coolant velocity & flow.
v) Define nozzle opening area.
vi) Calculate Head loss due to nozzle constriction.
vii) Design nozzle with drawing for manufacture.

2.1 Coolant Supply System

The Central Oil System pressure is derived from four Ingersoll Dual Stage Pumps that deliver 300 *gpm* each. One to four of these pumps are used as flow demand fluctuates to maintain a constant 180 psi to 200 psi system pressure [8]. A dedicated pump for an investment of under $10k to $15k could not match this central delivery system. Therefore, the best decision is to use the central system. The coolant used is CITGO Sentry 39 Straight Oil, with Benzgrind HP25

Concentrate added. The high lubricity straight sulferclorinated oil has a , μ , kinematic viscosity, of 7.10×10^{-4} ft^2/s , S_g , specific gravity, is 0.899, γ , the weight density, is 56 lb/ft^2 [9].

2.2 Grinding Wheel Velocity

The machine is Normac Model SD50. Figure 3 shows 7-in. diameter Resin Bonded Cubic Boron Nitride, CBN, wheels turning at a measured 7,010 *rpm*. The velocity of the wheel at the perimeter, v_w, is calculated to be

$$v = \pi \cdot d \cdot rpm$$

2.3 Pre-design Coolant Velocity and Flow Conditions

The coolant flow rate at the machine, with flow control valve 40% open, was measured to be 12.80 *gpm*. This flow rate with its corresponding coolant velocity was the standard setting. Higher flow rates, with the corresponding higher coolant velocities would cause the coolant supply lines to fly around uncontrollably, spraying oil all over the surrounding machines and operators.

2.4 Pre-design Maximum Coolant Velocity & Flow

The coolant flow rate at the machine, with flow control valve 100% open, was measured to be 31.25 *gpm*. The velocity of the coolant, v_{CM}, through the two 1/2 inch ID nozzles was calculated to be:

$$v_{CM} = 12.78\ ft/sec$$

2.5 Define Nozzle Opening Area

Given the supply flow rate, and knowing the velocity of the wheel, the acceptable nozzle opening area, A_N, could be given as

$$A_N = 0.047\ in^2$$

The primary coolant delivery nozzle's basic shape must conform to the shape of the wheel shown Figure 3.

2.6 Calculations of Head Loss and resulting Coolant Pressure at Nozzle

In order to calculate the Head Loss, H_L , the Reynolds number and friction factor must be established. Because of the shape of the wheel, the orifice of the nozzle has an Aspect Ratio above 4 to 1 [10]. Therefore, a derivation of the Reynolds number calculation must be made:

$$N_R = v \cdot D_b$$

$$N_R = 4251, \text{ slightly turbulence.}$$

And,

$$\frac{D_b}{\varepsilon} = 85$$

From the Moody Chart and other sources [7]

f = 0.051
K = 0.044, polished steel.

Therefore,

$$h_L = K \cdot \frac{v_2^2}{2g}$$

$$h_L = 0.146\ ft$$

The coolant pressure at the nozzle can be derived from the general energy equation of

$$\frac{P_1}{\gamma} + Z_1 + \frac{v_1^2}{2g} + H_A - H_R - H_L = \frac{P_2}{\gamma} + Z_2 + \frac{v_2^2}{2g}$$

Since,

$H_A = 0$, no additional energy from machine inlet to nozzle.

$Z_1 = Z_2 = 0$

$H_R = 0$, no actuators or motors removing energy on this circuit.

Then,

$$\frac{P_1}{\gamma} + \frac{v_1^2}{2g} - H_L = \frac{P_2}{\gamma} + \frac{v_2^2}{2g}$$

And,

$$P_2 = \gamma\left(P_1 + \frac{v_1^2 - v_2^2}{2g} - H_L\right)$$

$$P_2 = 135\ psi$$

Therefore the pressure is sufficient to break through the air barrier, while the coolant velocity is matched with the wheel velocity.

2.7 Nozzle Design

The nozzle orifice area, along with the wheel shape, dictates the design of the nozzle. The reduction angle of the nozzle is designed at 30° vertically and 15° horizontally. The throat in front of the orifice is half an inch long to get a smooth, even flow to minimize turbulence and to keep the coolant from fanning-out. All of the surfaces are polished to 32 RMS or better finishes. All of the transitions are blended and smoothed to help decrease turbulence, see Figure 6. The nozzle is made of a two piece construction to allow for fabrication with available resources. The top plate will be fastened by a series 6-32 countersink socket headed cap screws. Gasket material will be used between the plate and nozzle base.

2.8 Financial Analysis

The bottom line on product cost is as follows:

Inventory cost before:		$ 1.2717 per unit
Inventory cost after:	-	$ 1.2060 per unit
Savings per unit:		$ 0.0657 per unit (5% reduction)
Capacity Sold	x	234,000 units
Potential savings		$15,373.80 (product only)

The cost of implementing this system totals $750 ($50 materials + $700 labor). Engineering time is not included in this cost, this cost would be about $2400.

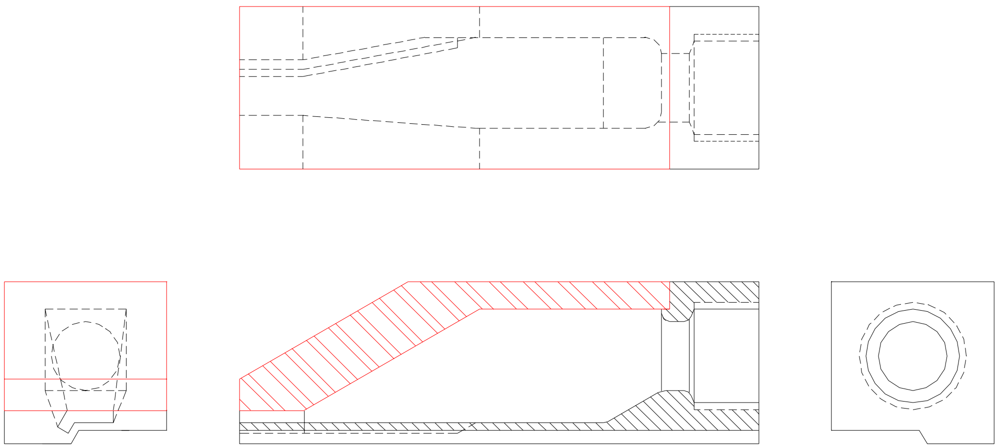

Figure 6: Nozzle Design Drawing

3. Conclusions

Many state of the art Numerical Control grinders are using sophisticated, high pressure, high cost coolant delivery systems. A quick inspection of most existing grinding equipment seems to indicate that the coolant systems were placed on the machines with little thought or interest. These systems were set-up to flood the workpiece and grinding wheel with oil or water-soluble coolant. Most of the machine tool builder’s emphasis during the eighties and early nineties was in machine rigidity, machine control, and grinding wheel development. These advancements in machine tool and wheel technologies, which utilize ever, increasing wheel velocities, can not be fully realized with insufficient coolant reaching the point of work.

The theory behind this is sound, as evidenced by the investments of large top end machine tool manufacturers such as S.E. Huffman Corporation. Implementing this coolant delivery system should increase the production of this machine by fifty percent or better. Setting up this type of system on other equipment with conventional, aluminum oxide, resinoid and vitrified grinding wheels could also increase their performance. Additional benefits, other than increased production, are improved part quality and reduced oil consumption. Reduced flow demand, and corresponding minimized demand on the central oil system, will also help diminish excess coolant mist on the manufacturing shop floor. This will aid in the plant-wide effort to improve air quality and overall work environment.

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