



Influence of hydraulic pressure on pipe ovality in the CNC machine threading process

Final Project

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Influence of hydraulic pressure on pipe ovality in the CNC machine threading process

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Abstract— Threading using CNC machining is widely used in the manufacturing industry to produce pipe threads. The hydraulic pressure applied during the threading process plays a crucial role in determining thread quality. Inappropriate hydraulic pressure can cause pipe cross-sectional deformation, known as pipe ovality, which reduces dimensional accuracy and product quality. This study aims to analyze the effect of hydraulic pressure on pipe ovality in the CNC threading process. The experimental method was carried out by measuring pipe ovality at various hydraulic pressure levels, and the data were analyzed using one-way ANOVA with hypothesis verification. The results show a clear relationship between hydraulic pressure and pipe ovality. At low pressure levels (400–700 psi), the ovality remains within acceptable tolerances. At medium pressure levels (850–1150 psi), the ovality approaches or exceeds the tolerance limit of 0.004 inches. At high pressure levels (≥ 1300 psi), excessive clamping force causes significant pipe deformation, so that the ovality value exceeds the allowable limit and causes rejection criteria.

Keywords: CNC threading, hydraulic pressure, pipe ovality, dimensional accuracy, one-way ANOVA.

I. INTRODUCTION

Pipe threading is a widely used manufacturing process for producing threaded pipes using a lathe. The turning process is performed using a CNC (Computer Numerical Control) machine, which has become a key technology in modern manufacturing, particularly in production processes requiring high levels of precision. One of the challenges often faced in the pipe turning process is the problem of ovality, namely, the change in the shape of the pipe from round to oval, due to various factors that occur during the process[1]. Excessive ovality in the pipe can cause dimensional inaccuracies,

reduce performance, and increase product failure rates, such as pipe leaks, which can ultimately impact production efficiency and manufacturing costs[2].

One of the factors that affects the ovality of the pipe in the threading process using a CNC machine is the hydraulic pressure applied during the material loading process. Hydraulic pressure is used to ensure that the pipe or material to be processed is clamped properly on the jaw or machine holder before the threading process is carried out. Improper application of hydraulic pressure can cause material settlement, especially changes in the shape of the pipe to become oval[1]. Therefore, understanding the effect of variations in hydraulic pressure on pipe ovality is very important to optimize the quality of the resulting product[3].

This study employed the one-way ANOVA method, which is used to test the mean/effect of a treatment in an experiment using a single factor, where one factor has three or more groups. The One-Way ANOVA method is used because this study aims to evaluate the effect of one process factor, namely hydraulic pressure, on changes in the average value of pipe ovality, with data divided into more than two pressure groups. It is called one-way because the researcher in his research is only interested in one factor or it can also be said that One-Way Anova (one-way analysis of variance) groups data based on one criterion only, for example, wanting to know if there is a real difference between the average of three groups of data, and the statistical test used is the F test[4]. To ensure the reliability of the observed differences between the three pressure groups, a One-Way Analysis of Variance (ANOVA) was used. There were three different sample groups, each consisting of 15 measurement samples, resulting in a total of 45 data points. ANOVA is appropriate for this type of experimental design because it compares the average responses across multiple groups to determine if there are statistically significant

differences between them, while accounting for internal data variability. This approach is widely recognized in engineering process analysis as a reliable method to assess the influence of a single process variable on a performance output[5].

By understanding this study, it is hoped that optimal hydraulic pressure parameters can be identified and pipes of better quality and greater accuracy can be produced. Furthermore, this study will likely contribute to increased efficiency and effectiveness in the manufacturing process by reducing the potential for product defects and increasing production success rates[6].

II. METHOD

A. Materials and tools

The materials and tools used in this study are: Pipe octg, MRP, Mazak CNC threader machine, and hydraulic compressor.

1. Pipe OCTG

OCTG (Oil Country Tubular Goods) pipes are special pipes used in the oil and gas industry, including casing, tubing, and drill pipes to support the drilling process, production, and fluid transportation. One of the main features of OCTG pipes is the use of thread connections, which is a method of connecting pipes through precision threads at the end of the pipe. Premium type joints handle points in a more precise manner with better geometry on thread and shoulder profiles, and better sealing capabilities. Threaded pipe joints are commonly used to connect risers, tendons, drill pipes, and well casing strings[7]. In these applications, fatigue resistance plays a critical role. A wide variety of patented design features are available, all claiming to increase the fatigue life of the connection[8]. These connections are designed to ensure structural strength, fluid tightness, and ease of installation in extreme environments, such as the high pressures and extreme temperatures in oil or gas wells. Threaded connections are divided into two main types: API standard threads (such as API Buttress and API Round) for general applications, and premium threads that offer higher performance with a gas-tight design, wear resistance, and additional stability for more demanding working conditions[9].

Figure 1 shows the OCTG pipe used in this study. This study used a sample of L80 Type 1 carbon steel pipe. L80 Type 1 steel is classified as a medium carbon steel with high tensile strength and resistance to harsh well conditions. This steel is included in the API 5CT standard, an international technical specification for OCTG pipe issued by the American Petroleum Institute (API). The diameter used is 3.5 inches, with a wall thickness of 0.254 inches[10].



Figure 1. Carbon steel pipe with grade L80 type 1

2. MRP Ovality



Figure 2. MRP Ovality

Figure 2 shows the tool used in the study, namely MRP. Handling deficiencies and defects that occur during construction projects, especially in piping fabrication, requires high cost and time. The current quality management process related to piping fabrication has several limitations, most of which are caused by human error and consistency violations[11]. Precision measuring instruments are used during handling to avoid defects in the pipe construction process. A Mechanical Rotating Probe (MRP) with a standard block is used to measure overall ovality by recording the difference between the maximum and minimum pipe diameters.

3. Mazak CNC threader machine

The Mazak CNC threader machine is a special tool designed for the threading process of OCTG pipes with premium threads that meet the high standards of the oil and gas industry. This machine integrates precision numerical control technology to ensure that each thread produced has consistent and accurate dimensions[12]. The Mazak Premium Threader is equipped with a spindle that is capable of rotating at high speeds, allowing for high-efficiency thread cutting with good quality.

This machine is designed to produce premium threads with very tight tolerances, including API thread types and proprietary premium thread connections, which are often

used on casing and tubing pipes. In addition, the hydraulic chuck system on this machine ensures that the pipe remains stable during the threading process, reducing the risk of ovality or deformation. With the ability to program various thread profiles, this machine is capable of producing threads with varying bevel angles, pitches, and depths according to the requested specifications[12].

4. Hydraulic compressor

A hydraulic compressor is a tool that uses hydraulic pressure to compress fluid or air into a particular system. Hydraulic systems work according to the principle that the pressure exerted by a confined liquid is transmitted to the internal face of its container[13]. The working principle of a hydraulic compressor involves hydraulic fluid being pumped by a piston through a high-pressure line. This fluid then provides precisely controlled pressure, allowing the hydraulic system to produce strong and stable thrust or clamping force. This tool usually consists of main components such as a hydraulic pump, pressure regulating valve, fluid reservoir, and actuator. This hydraulic compressor has a pressure limit of up to 3000 psi.

B. Research Flowchart

The flow of this research begins with the problem identification stage, namely the discovery of the ovality issue in the pipe that occurs during the threading process using a CNC machine. Based on these problems, the research objectives are determined, namely, to study the effect of hydraulic pressure on changes in ovality in the pipe. Furthermore, the selection of pipe materials and measuring instruments is carried out according to the needs of the experiment, followed by the design of research methods with variations in pressure and CNC parameters. The threading process is then carried out on a CNC machine according to the specified parameters. After the process takes place, the ovality of the pipe is measured to determine the level of deformation that occurs. The measurement data are then collected and analyzed using the testing technique and ANOVA methods to evaluate the relationship between hydraulic pressure and pipe ovality. This entire series of activities is arranged to obtain conclusions that support the research objectives scientifically and objectively. Figure 1 explains the work stages or sequence of work that the author will carry out during this research. Figure 3 shows the flowchart used in this study.

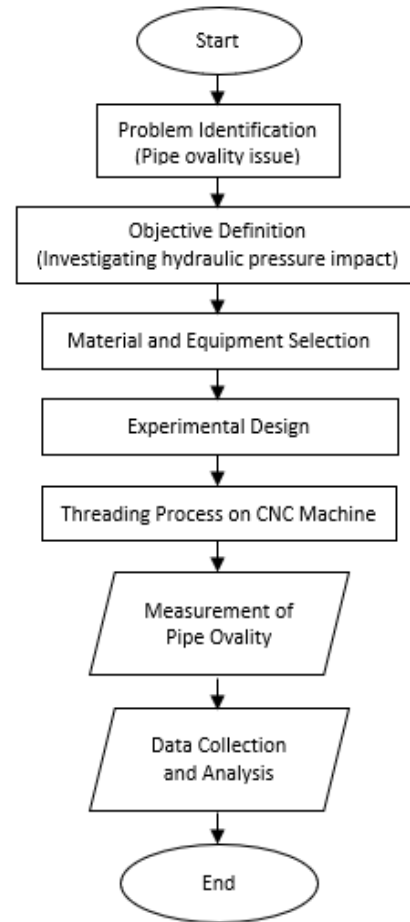


Figure 3. Research Flowchart: Influence of hydraulic pressure on pipe ovality in the CNC machine threading process.

C. Testing techniques

a. Parameter Ovality

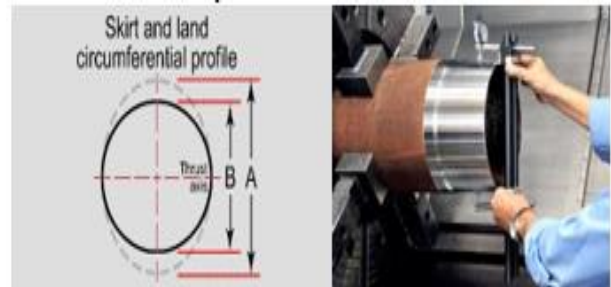


Figure 4. Parameter ovality

Figure 4 shows a picture of the ovality measurement. Ovality in OCTG threaded pipe is the difference between the maximum and minimum diameters in the cross-section of the pipe, which is calculated to determine the extent to which the pipe shape deviates from a perfect circle[14].

Ovality is calculated with a simple formula:

$$\text{Ovality} = \text{Largest diameter} - \text{Smallest diameter} \dots \text{Eq (1)}$$

The distance between the largest diameter and the smallest diameter. For example, in the MRP reading, the largest diameter is 10 thou, and the smallest is -2 thou, then the ovality value is 12 thou. And the results are compared to standard tolerances on the inspection report (for example, 12 thou or 0.012 inches).

b. Experimental variable

In the experimental table, some variables and values will be tested, as shown in Table 1.

Table 1. Experimental variable table

Variable Type	Variable Name	Value or Level
Predictor	Hydraulic Pressure	Low (400-700 psi), Medium (850-1150 psi), High (≥ 1300 psi)
Response	Ovality (inch)	Measured after the CNC threading process
Criteria	Accept/Reject	Accept: Ovality 0 - 0.004 Inch Reject: > 0.004 Inch

c. Test table

At each hydraulic pressure variation, 5 samples at each pressure level will be run for a total of 45 samples, as shown in Table 2.

Table 2. Test table

Range Pressure Value(psi)	Ovality(in)	Result Criteria
Low 400-700	400	5 samples
	550	5 samples
	700	5 samples
Medium 850-1150	850	5 samples
	1000	5 samples
	1150	5 samples
High ≥ 1300	1300	5 samples
	1450	5 samples
	1600	5 samples

d. One-Way ANOVA Method

This test is used to see if there is variation in the means of three or more groups. This type of test is used when the data set has only one independent variable. If the test statistic exceeds the critical value, the null

hypothesis is rejected, and the means of at least two groups are statistically significantly different[4].

The effect of hydraulic pressure on pipe ovality was evaluated using a one-way Analysis of Variance (ANOVA). The statistical model is expressed as:

1. Hypothesis

- H_0 (Null hypothesis):

There was no significant difference in mean ovality between pressure groups.

$$(\mu_1 = \mu_2 = \mu_3)$$

- H_1 (Alternative hypothesis):

There is at least one pressure group that has a different mean ovality.

$$(\mu_i \neq \mu_j \text{ for at least one pair } i \neq j)$$

2. Data summary

The average of each group and the overall average

3. Variation Between Groups (SSB – Sum of Squares Between)

$$SS_{Between} = \sum_{i=1}^k n_i (\bar{X}_i - \bar{X}_{total})^2 \dots \text{Eq (2)}$$

With $n = 15$ (number of samples per group)

4. Variation Within Groups (SSW – Sum of Squares Within)

$$SS_{Within} = \sum_{i=1}^k \sum_{j=1}^n (x_{ij} - \bar{X}_i)^2 \dots \text{Eq (3)}$$

5. Degrees of Freedom

- Between groups: $df_{between} = k - 1$
- Within groups: $df_{within} = N - k$
- Total = $df_{total} = N - 1$

6. Mean Squares

Formula:

$$MSB = \frac{SSB}{df_{between}} \dots \text{Eq (4)}$$

$$MSW = \frac{SSW}{df_{within}} \dots \text{Eq (5)}$$

7. F-Statistic

Formula:

$$F = \frac{MS_{Between}}{MS_{Within}} \dots \text{Eq (6)}$$

8. P value

$$\alpha = 0.05$$

At a significance level of 0.05, if the p-value is lower than α , then reject H_0 , which means there is a statistically significant difference.

III. RESULT AND DISCUSSION

This section presents the experimental results and statistical evaluation of pipe ovality for various hydraulic pressure levels during the CNC threading process, assessing the significance of pressure on dimensional accuracy.

A. Result of Measurement

The measurement results for each group at different pressures will be displayed in Table 3.

Table 3. Result value of the test table

Range Pressure Value(psi)		Ovality(in)	Result Criteria
Low 400-700	400	0.0005	Accept
		0.001	Accept
		0.001	Accept
		0.0015	Accept
		0.0005	Accept
	550	0.002	Accept
		0.0015	Accept
		0.001	Accept
		0.0015	Accept
		0.002	Accept
	700	0.002	Accept
		0.0025	Accept
		0.0015	Accept
		0.0025	Accept
		0.002	Accept
Medium 850-1150	850	0.0025	Accept
		0.003	Accept
		0.0035	Accept
		0.004	Accept
		0.003	Accept
	1000	0.0045	Reject
		0.004	Accept
		0.0035	Accept
		0.0045	Reject
		0.004	Accept
	1150	0.005	Reject
		0.0055	Reject
		0.0045	Reject
		0.0055	Reject
		0.0045	Reject
High ≥1300	1300	0.006	Reject
		0.0045	Reject
		0.0065	Reject
		0.006	Reject
		0.0055	Reject
	1450	0.007	Reject
		0.008	Reject
		0.007	Reject
		0.0075	Reject
		0.0065	Reject
	1600	0.008	Reject
		0.009	Reject
		0.0075	Reject
		0.0085	Reject
		0.0075	Reject

1. Data Summary

Table 4. Average of each pressure

Pressure Level	Ovality (in)	Mean (\bar{x})
Low	0.0005, 0.001, 0.001, 0.0015, 0.0005, 0.002, 0.0015, 0.001, 0.0015, 0.002, 0.002, 0.0025, 0.0015, 0.0025, 0.002	0.00153
Medium	0.0025, 0.003, 0.0035, 0.004, 0.003, 0.0045, 0.004, 0.0035, 0.0045, 0.004, 0.005, 0.0055, 0.0045, 0.0055, 0.0045	0.0041
High	0.006, 0.0045, 0.0065, 0.006, 0.0055, 0.007, 0.008, 0.007, 0.0075, 0.0065, 0.008, 0.009, 0.0075, 0.0085, 0.0075	0.007

Overall (Grand Mean):

N= 45

$$\bar{X}_{grand} = \frac{0.1895}{45}$$

$$\bar{X}_{grand} = 0.00421$$

The purpose of finding the average for each group is to find out the average ovality at each pressure level, and to be the basis for calculating SSB and SSW. The grand mean is used to measure how far the mean for each pressure deviates from the overall average condition.

2. Variation Between Groups (SSB – Sum of Squares Between)

$$SS_{Between} = \sum_{i=1}^k ni (\bar{X}_i - \bar{X}_{total})^2$$

With n = 15 (number of samples per group)

$$SSB = [15(0.00153 - 0.00421)^2 + 15(0.0041 - 0.00421)^2 + 15(0.007 - 0.00421)^2]$$

$$SSB = 0.0001077 + 0.00000018 + 0.0001165$$

$$SSB = 0.00022441$$

SSB is used to calculate the total value of variation between groups, showing the magnitude of variation caused by pressure.

3. Variation Within Groups (SSW – Sum of Squares Within)

$$SS_{Within} = \sum_{i=1}^k \sum_{j=1}^n (x_{ij} - \bar{X}_i)^2$$

Table 5. SSW – Sum of Squares Within

Level	Calculation Result
Low	0.000005735
Medium	0.000011100
High	0.000020000
Total SSW	0.00003683

SSW is used to calculate the total value of variation within a group, measuring variation due to natural machine factors.

4. Degrees of Freedom

- Between groups: $df_{between} = k - 1 = 3 - 1 = 2$
- Within groups: $df_{within} = N - k = 45 - 3 = 42$
- Dftotal = $N - 1 = 45 - 1 = 44$

Normalize SSB and SSW to mean square and to determine the F distribution used.

5. Mean squares

$$MSB = \frac{0.00022441}{2} = 0.00011221$$

$$MSW = \frac{0.00003683}{42} = 0.00000877$$

MSB: average variation between groups per one degree of freedom.

MSW: average variation within groups per one degree of freedom.

6. F-Statistic

$$F = \frac{0.00011221}{0.00000877} = 127.94$$

Compared with the F critical and calculating the p-value

7. P-value and decision

Using the F-distribution with $(df_1, df_2) = (2, 42)$, the p-value is:

$$p \approx 1.36 \times 10^{-18} = (< 0.001)$$

At significance level $\alpha = 0.05$, the critical F from the tables is approximately

$$F_{crit}(2,42) \approx 3.22$$

Since:

$$F_{calculated} = 127.94 > F_{crit} = 3.22 \text{ and } p = < 0.05,$$

One-way ANOVA analysis showed a statistically significant effect of hydraulic pressure level on pipe ovality ($F(2,42) = 127.94, p < 0.05$). Therefore, the null hypothesis was rejected.

Using a 3.5-inch diameter, 0.254-inch wall thickness L80 Type 1 carbon steel pipe sample. Each test was conducted at varying hydraulic pressure levels, ranging from 400 psi to 1600 psi, which represents the clamping pressure applied by the hydraulic chuck of the Mazak Premium Threader CNC machine. This machine integrates precision numerical control technology to ensure that each thread produced has consistent and accurate dimensions[12].

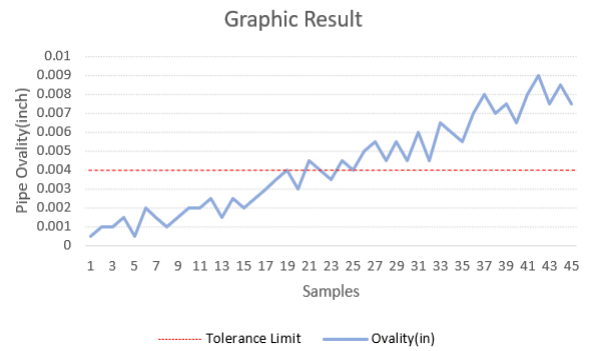


Figure 5. Sample measurement results graph

The graphical result (Figure 5) shows a progressive increase in pipe ovality across the measured samples, indicating the influence of increasing hydraulic clamping pressure during the CNC threading process. The solid blue line represents the measured ovality for each sample, while the red dashed line at approximately 0.004 inches indicates the maximum allowable tolerance based on dimensional inspection standards. Although the overall trend shows a near-linear increase in ovality, local fluctuations are observed in the mid-range samples, reflecting transitional process behavior. Based on the relationship between ovality values and the tolerance limit, the process response can be divided into three distinct regions:

- Stable Region (Samples 1–15):

In this region, the applied pressure is 400–700 psi, and all ovality values remain consistently below the tolerance limits. The pipe maintains its geometric integrity, indicating that the applied hydraulic pressure is sufficient to secure the material without causing excessive ovality.

- Transition Fluctuation Region (Samples 16–26):

In this interval, at a pressure of 850 psi, ovality values show significant variation, with some samples exceeding the tolerance limit, such as samples 22 and 25. However, the behavior is not consistently out of tolerance. This variation indicates the onset of hydraulic pressure distribution and increasing ovality values.

- Out-of-Tolerance Region (Samples ≥ 27):

In this region, starting from pressures of 1000-1600 psi, the measured ovality values consistently exceed the permissible tolerance limits. This indicates that the applied hydraulic clamping pressure is too high for the pipe material. Excessive clamping force results in high ovality in the pipe. Consequently, dimensional accuracy cannot be maintained, and the risk of product rejection increases significantly. This condition confirms that operating the CNC threading process beyond this point is unsuitable for quality production.

This trend shows that higher hydraulic pressure during clamping causes more significant pipe deformation, exceeding the tolerance limit of 0.004 inch.

B. Statistical Analysis One-Way ANOVA

The analysis was performed under the following hypotheses:

- Null Hypothesis (H_0): There is no significant difference in mean ovality between the three pressure groups. Any differences observed are due to random variation or measurement error.

$$(\mu_1 = \mu_2 = \mu_3)$$

- Alternative Hypothesis (H_1): At least one of the pressure groups produces a mean ovality value that significantly differs from the others.

$$(\mu_i \neq \mu_j \text{ for at least one pair } i \neq j)$$

The analysis yielded the following results:

- Mean:
 - Low pressure: 0.00153
 - Medium pressure: 0.0041
 - High pressure: 0.007
 - Overall (grand mean): 0.00421
- Sum of Squares Between Groups (SSB): 0.00022441
- Sum of Squares Within Groups (SSW): 0.00003683
- Degrees of Freedom: Between: 2, Within: 42, dftotal: 44
- Mean Square Between (MSB): 0.00011221
- Mean Square Within (MSW): 0.00000877
- F-statistic: 127.94
- p-value:
 - $p \approx 1.36 \times 10^{-18} = (< 0.001)$
- $F_{crit} (2,42) \approx 3.22$
- $F_{calculated} = 127.94 > F_{crit} = 3.22$ and $p = < 0.05$,
- Decision:
 - Reject the null hypothesis H_0 (that all group means are equal). There is a statistically significant difference between the group means.

The analysis revealed a highly significant difference ($p < 0.05$) between the groups, indicating that changes in hydraulic pressure caused significant variations in ovality. The calculated F-value was significantly greater than the critical F-value from the statistical table, confirming that hydraulic pressure had a statistically significant effect on pipe ovality[15].

In practical terms, this means that increasing hydraulic pressure did not simply cause small, random fluctuations in ovality but resulted in systematic, measurable changes in pipe geometry. The between-group variance (the difference in average ovality across different pressure levels) was significantly greater than the within-group variance (the difference between samples within the same pressure range). This clearly indicates that hydraulic pressure was the primary driver of deformation behavior, rather than random machining inconsistencies or measurement uncertainties.

These findings provide strong statistical evidence supporting the experimental observation that pipe ovality consistently increases with higher hydraulic pressure.

IV.CONCLUSION

This study confirms that hydraulic pressure has a significant and measurable effect on pipe ovality during the CNC threading process on OCTG carbon steel pipe. After measuring 45 samples with different pressure variations, and measuring using the MRP measuring instrument, the analysis shows a clear correlation between the increase in clamping pressure and the degree of geometric deformation in the pipe body.

At low hydraulic pressures (400–700 psi), ovality values increase but remain measured below the maximum tolerance limit of 0.004 inches specified in the inspection report standard. Within this range, the pipe is securely and stably clamped during the threading process. As pressure increases to the mid-range of 850 psi, ovality values show significant variation, with some samples exceeding the tolerance limit. However, ovality values are not always out of tolerance. This pressure is categorized as initial deformation or the initial rejection zone. At higher pressures (1000–1600 psi), measured ovality values consistently exceed the allowable tolerance limit. Ovality increases dramatically, reaching 0.009 inches in sample 42 at 1600 psi, resulting in complete geometric distortion and product rejection.

Statistical validation using One-Way ANOVA confirmed that the variation in ovality across pressure levels was highly significant ($p < 0.05$)[4]. This indicates that the differences were not caused by random measurement errors or machining inconsistencies, but were directly caused by variations in hydraulic pressure. These results confirm the experimental observation that excessive hydraulic pressure causes measurable ovality deformation in each pipe sample. This study is expected to contribute to improving the efficiency and accuracy of the CNC machine threading process.

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