

Engineering Design of A Gang Drilling Machine Equipped with Jig and Fixtures to Make A Prototype Machine in Birdcage Production

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Abstract—This paper is dealing with the engineering design of a gang drilling machine with jig & fixtures to make a prototype machine. This effort has been done in order to solve the problem which aroused in small business enterprises producing birdcages. The problem was how to minimize the production time in making a lot of holes that have same distance and straightness. Hopefully, the prototype machine can help the small business enterprises to increase their production rate. The design engineering process has been carried out by variant approximation on dowel pin modular fixtures in order to simplify fixtures design. CAD CAM software has also been used as fixtures synthesized method including geometric analysis and three dimensional fixtures assembling. The resulting prototype machine can be well operated and based on the running test, it can be concluded that the greater the motor rotation the greater the power needed. As for teak wood, at 250 rpm motor rotation the power needed is 26.5 watt, and at 400 rpm the motor needs power of 43.6 watt while at 600 rpm the motor needs power of 600 watt. The power consumption is also depends on the type of material, the better the mechanical properties of the materials, the higher the power consumption. For cast iron, the 400 rpm motor rotation needs power as high as 569.7 watt. This prototype of gang drilling machine needs power of 350 watt to make five holes on teak wood while ordinary drilling machine needs total power of 1350 watt.

Keywords—birdcage, fixtures, gang drill, jig, small business

Abstrak—Makalah ini membahas mengenai rekayasa prototipe gang drill dengan jig & fixturnya, untuk mengatasi salah satu permasalahan yang ada di UKM sangkar burung, di dalam proses pembuatan sangkar burung, perlu adanya penerapan teknologi tepat guna yang berupa satu unit mesin gang drill dengan jig & fixturnya yang mampu membuat lubang yang banyak, dengan jarak dan kelurusan yang sama secara cepat, sehingga produksi UKM sangkar burung dapat ditingkatkan. Pengembangan metode perancangan dan modifikasi fixture dengan pendekatan varian pada modular fixture berbasis dowel pin juga bisa memudahkan dalam perancangan fixture. Software CAD CAM dapat digunakan sebagai metode sintesis fixture termasuk analisis geometri, perencanaan dan perakitan fixture secara 3 dimensi dengan cepat. Mesin gang drill dengan jig & fixture, hasil rekayasa dapat bekerja dengan baik dan berdasarkan hasil pengujian makin tinggi putaran motor, maka makin besar daya yang dibutuhkan, untuk bahan kayu jati pada putaran 250 rpm, daya yang dibutuhkan sebesar 26,5 W dan pada putaran 600 rpm daya yang dibutuhkan 600 W. Juga kebutuhan daya pada proses drilling, juga tergantung jenis bahan yang akan diproses, makin tinggi harga sifat mekanik bahan, maka kebutuhan daya untuk proses drilling makin besar. Kebutuhan daya untuk proses drilling pada bahan kayu jati dengan putaran motor 400 rpm sebesar 43,6 W, sedangkan untuk bahan besi tuang dengan putaran motor 400 rpm sebesar 569,7 W. Kebutuhan waktu dan daya dalam pembuatan 5 lubang dengan bahan kayu jati menggunakan mesin gang drill 1 motor 5 pahat jauh lebih rendah, bila dibanding dengan drill 1 motor 1 pahat sebesar 350 W dan 1350 W. Hal ini mesin gang drill 1 motor 5 pahat menjadikan produktivitas UKM produk sangkar burung akan meningkat.

Kata Kunci—sangkar burung, fixture, gang drill, jig, industri kecil

I. INTRODUCTION

The management of fixtures system in machining remain relatively stagnant especially the progress of technology development. This condition governs to the needs of scientifically-based management of model formalization which can give significant contribution to the development of fixture systems [1].

The development of design method and fixtures modification using variant approximation based on dowel pin modular fixtures can also make fixtures design easier [2].

CAD/CAM/CAE/CAT softwares can be used as fixture synthesized method including geometric analysis, design and assembling of fixture in three dimensional mode [3-4].

Expert system has been developed for designing the fixtures which can be used as a basic guide in designing and assembling the appropriate fixtures [5].

When assembling fixture in a machining process, the workpiece position, tool movement, pin/locator flexibility have to be considered so that the elements of jig and fixture will be interchangeable and reusable [6].

Designing and assembling of jig and fixture can be carried out using finite element method, then simulated by the ANSYS software [7]. Carbon fiber composite has been used as the material of jig and fixture in car assembling [8].

This paper deal with the engineering design of a gang drill prototype in order to help some small enterprises

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that produce birdcage to solve their problem. Their problem was how to drill many holes in one step, how to maintain the same distance between holes, and how to maintain the holes straightness. In the past, the drilling process was done one by one for each hole so that the drilling process was very exhausted [9].

This gang drillig machine is equipped with jig and fixtures specially in the type of drilling jig, which control the relationship between work piece and cutting tool. Meanwhile, the fixtures in this machine is used as the clamping elements for gripping the work piece.

To realize this engineering process, it would require the calculation of the main components such as shaft, gear, bearing and spring and pin.

The following equation is used for the shaft calculation [10-12]:

$$D \geq \sqrt[5]{\frac{16^2 Mb^2 + 16^2 Mt^2}{\pi^2 \left(\frac{K_s \cdot Syp}{N}\right)^2}} \quad (1)$$

After obtaining the shaft diameters and materials used, so one can determine the shaft to get the long life usage.

Gears are used to transmits power and rotational motion between two shafts arranged parallel. The type of the gear used in this design is the straight spur gears, which has the in the following equations to used in the engineering process [1,12].

To obtain the rotation of the gear (n_2),

$$\frac{n_2}{n_1} = \frac{d_1}{d_2} \quad (2)$$

The number of teeth (N_t) can be calculated as follows,

$$P = \frac{Nt}{d} \quad (3)$$

When two gears are in mesh, the distance between the center of the two gears (C_1), is equal to one half the sum of their pich diameters. In equation form [11],

$$C_1 = \frac{d_1 + d_2}{2} \quad (4)$$

In Figure 1, the center distance (C_1), is shown. And the ratio r_v between gears,

$$r_v = \frac{n_2}{n_1} = \frac{Nt_1}{Nt_2} = \frac{d_1}{d_2} \quad (5)$$

The equations bellow is used to find the torque (T) and the tangential force (F_t),

$$T = \frac{Hp \cdot 63000}{n} \quad (6)$$

$$Ft = \frac{T}{d / 2} \quad (7)$$

Before getting a dynamic load, it is necessary to get the peripheral speed (vp),

$$vp = \frac{\pi d n}{60} \quad (8)$$

The dynamic effect on gear teeth, due to such factors as inaccurately cut teeth, improper tooth spacing, improper mounting, deflection due to elasticity of the gears and shaft, and irregular load requirements must be taken in account in this preliminary design stage. The dynamic load (Fd) can be calculated by,

$$Fd = \frac{600 + vp}{600} Ft$$

(9)

for $0 \leq vp \leq 2000ft/min$

So that the width of the teeth (b) of gears can be obtained by the following equation,

$$b = \frac{Fd}{d \cdot Q \cdot k} \quad (10)$$

$$Q = \frac{2 \cdot Nt_1 \cdot Nt_2}{Nt_1 + Nt_2} \quad (11)$$

In order to prevent the gear damage, hence one shall have to know the size of the working load, that is :

$$Fb = \frac{S \cdot b \cdot Y}{P} \quad (12)$$

$$\sigma_t = \frac{F_t \cdot K_o \cdot P \cdot K_s \cdot K_m}{K_v \cdot b \cdot J} \quad (13)$$

and,

$$S_{ad} = \frac{S_{at} \cdot K_L}{K_T \cdot K_R} \quad (14)$$

Bearings should have also been chosen appropriately by determining the working load and life of the bearings [10, 13].

$$Ft = \sqrt{F_{BH}^2 + F_{BV}^2} \quad (15)$$

$$P = V \cdot Ft \quad (16)$$

Bearings lifetime,

$$L_{10h} = \left(\frac{C_2}{P_1}\right)^b \times \frac{10^6}{60 \cdot n} \quad (17)$$

Pins have also need to be taken into account, so that damage can be prevented. In the design of the pin, the effect of the shear and the compressive stress needs to be considered [13].

Review to the shear stress

$$\frac{K_s \cdot Syp}{N} \geq \frac{2T}{D \cdot W \cdot L_{min}} \quad (18)$$

Review to the compressive stress,

$$\frac{K_c \cdot Syp}{N} \geq \frac{4T}{D \cdot H \cdot L} \quad (19)$$

Spring is an important component, with the primary function of a spring is to absorb shock and to support the weight of the machine. To determine the dimensions of the corresponding spring, the spring correction factors diagram in Figure 2 can be used.

Spring ratio (C_3),

$$C_3 = \frac{D}{d} \quad (20)$$

$$K_w = \frac{4C_3 - 1}{4C_3 - 4} + \frac{0,615}{C_3} \quad (21)$$

Planned maximum deflection of the spring by 4.6 ins, so that deflection clash allowance Y_{clash} is 10% of the Y_{op-max}

$$Y_{clash} = 10\% \times Y_{0-max} \quad (22)$$

Length of solid spring L_s ,

$$L_s = L_f - (Y_1 + Y_{op-max} + Y_{clash}) \quad (23)$$

The number of coil springs (N_t),

$$N_t = \frac{L_s}{d} \quad (24)$$

Because the springs are squared and ground end, the winding number is two not active. So the number of active coils (N_a) is,

$$N_a = N_t - 2 \quad (25)$$

Since the spring is experiencing the beginning deflection, then spring is in static conditions has received a static force. If the specified used shear modulus $G = 11.5 \times 10^6$, then the static force that resulted in large initial deflection to:

$$P_{min} = P_{static} = \frac{11.5 \times 10^6 \times d^4 \times y_1}{64 \times N_a \times R^3} \quad (26)$$

Furthermore, from load fluctuations can be determined the average load ($P_{mean} = P_m$) and load amplitude ($P_{range} = P_r$) as follows,

$$P_m = \frac{P_{max} + P_{min}}{2} \quad (27)$$

$$P_r = \frac{P_{max} - P_{min}}{2} \quad (28)$$

From both value to get comparison between P_r and P_m as follows:

$$\frac{P_r}{P_m} = \frac{1}{1.25} = \frac{\tau_r}{\tau_m} \quad (29)$$

Average shear stress (τ_a) that occurs at,

$$\tau_m = K_w \frac{16 \cdot P_m \cdot R}{\pi \cdot d^3} \quad (30)$$

The shear stress amplitude (τ_a) is known from the comparison between the average shear stress and amplitude. Shear stress amplitude value,

$$\tau_a = \frac{\tau_m}{1.25} \quad (31)$$

II. METHOD

Prototype of gang drilling machine is equipped with Jig & Fixture, is an engineered effort to increase production of the bird cage small business (see Figure 3).

A. Materials Test

Materials used in this study, in determining the speed of drilling and power requirements are teak, aluminum, brass and cast iron that have mechanical properties, such as Table 1.

B. Research Flowchart

In order to design the prototype of gang drill equipped with jig & fixture, it is necessary to have some steps as, shown in the flow chart in Figure 4.

C. Examination

In order to get a gang drill machine which is able to work properly, the testing by varying the material and rotational speed are conducted. Therefore, the power requirements for fine drilling chisels work

simultaneously are known. Five rotational speed (150 rpm, 250 rpm, 400 rpm and 1450 rpm) are used in the experiments while the tested materials are teak wood, aluminum, brass and cast iron. Every drilling process for certain material and rotational speed is carried out with 5 (five) times iteration.

To find out, how much gang drilling machine can be useful for small business in order to improving productivity, verification of drilling speed and power requirements are performed for single chisel drilling machine with a single motor gang drill. Therefore, time difference and resources required in the drilling process between them can be known. Tests is carried out by varying the number of chisel drill (1 pieces, 2 pieces, 3 pieces, 4 pieces and 5 pieces) and materials (teak wood, aluminum, brass and cast iron). Each test is iterated five time.

III. RESULTS AND DISCUSSION

Based on the calculations, the countershaft and the driven shaft have the dimension, which are listed in Figure 5 and 6, respectively. Where as the specifications are given in Table 2.

Furthermore, the straight gears are used to transmit power and rotary motion between the two shaft which are arranged parallelly as shown in Figure 7 and 8. The specification of the gears are given in Table 3.

As for bearings, roller bearings (ball bearings, single row- deep groove) are chosen with the specification in Table 4. The Pin and spring are specified in Table 5 and 6 respectively.

Based on the results of testing by varying the rotational speed and test materials, the power requirements for 5 (five) drilling chisels that work in conjunction, can be seen in Table 7.

It can be observed from Figure 9 that the power consumption is needed for the higher rotation. As for teak wood, the rotation of 250 rpm and 600 rpm consume the power of 26.5 W and 600 W, respectively. Motor rotation speed has significant effect to cutting speed, force and torque. The greater the motor rotation, the higher the cutting speed. However, the power demand also increase of force and torque.

By observing Figure 9, it can be known that there are some differences on the power requirements for different materials. Cast iron consumes the higher while teak wood pays the lower one for the some motor rotation due to the different of mechanical properties.

The differences between the two drill machines lies on the construction design. The first type is the gang drill machine with one motor and five chisel. A single main shaft with four driven-shaft and four link-gear are used as the power transmission system. On the other hand, the second type, which is the original machine used by small business, uses a motor with single chisel and the driven-shaft only.

Figure 10 reveals as the power requirement for manufacturing five holes on the different material using the two type gang drill machines (see Figure 11), while Figure 12 inform the time needed to finish that tasks. When five chisel work simultaneously using gang drill machine, both time and power requirement are reduced compare to drilling process using single chisel.

Therefore, gang drill machine has increased productivity and efficiency of birdcage manufacturer.

IV. CONCLUSION

1. Prototype of gang drill equipped with a jig & fixture, has been made and tested. Testing should that the machine can be functionalized properly.
2. The higher the motor rotation, the greater of power needed. For teak wood at 250 rpm requires power of 26.5 W. At the higher rotaton of 600 rpm, the greather power of 600 W consumed.
3. Power requirements of the drilling process, depends on the mechnal properties of materials. Materials with higher mechanical properties consume more

power in order to accomplish the process than lower ones. For rotation at 400 rpm, teak wood need power of 43.6 W only while cast iron spending power of 569.7 W

4. Power requirements to make 5 holes for teak wood using gang drill machine with 1 motor and 5 chisels is lower than the ordinary/original machine 1 motor and 1 chisel.
5. The drilling time to make 5 holes using gang drill machine is shorter than the ordinary machine.

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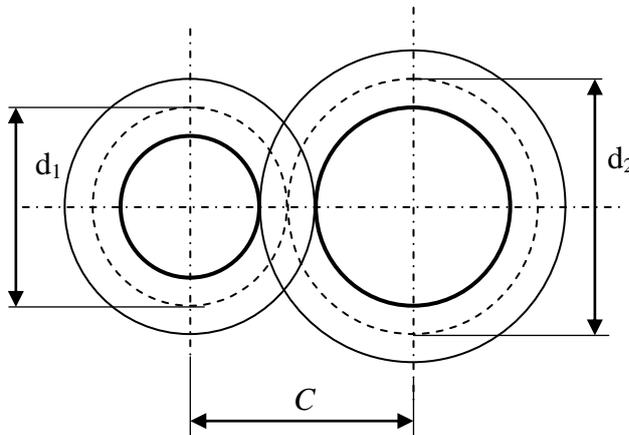


Figure 1. The center distance (C₁)

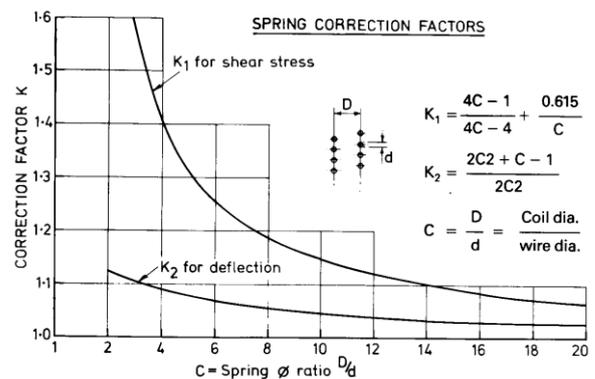


Figure 2. The spring correction factors diagram [14]

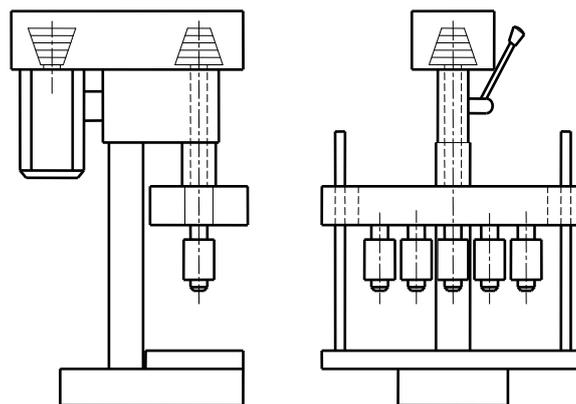


Figure 3. Prototype of gang drilling machine is equipped with jig and fixture

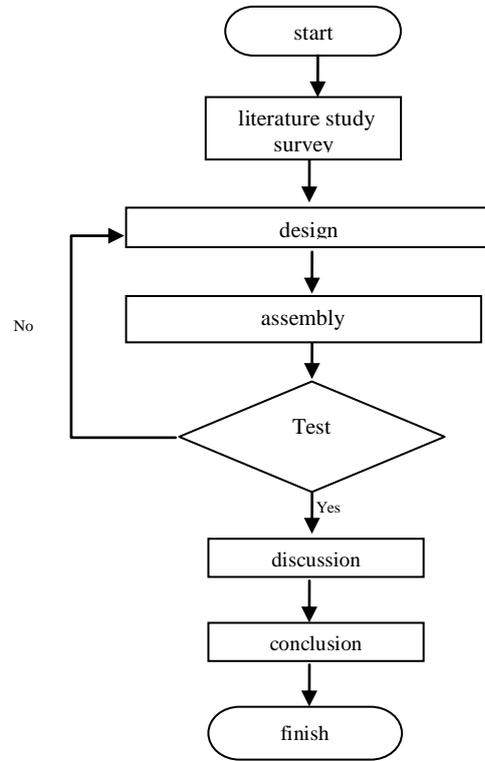


Figure 4. Research methodology flowchart

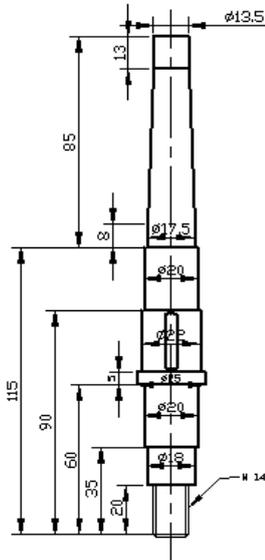


Figure 5. Countershaft

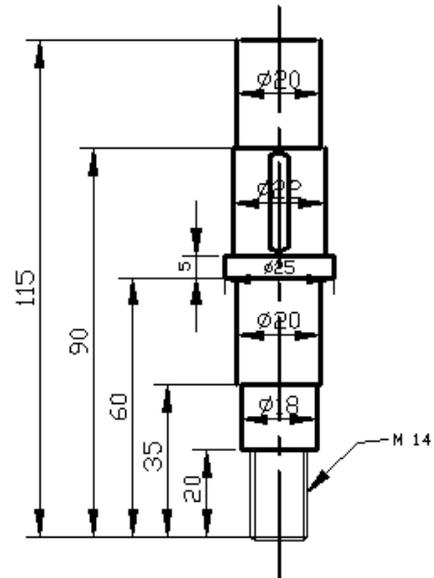


Figure 6. Driven shaft

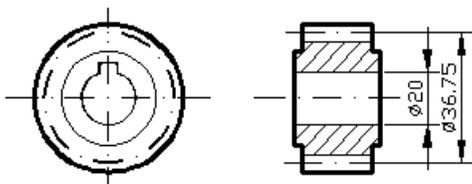


Figure 7. Pinion

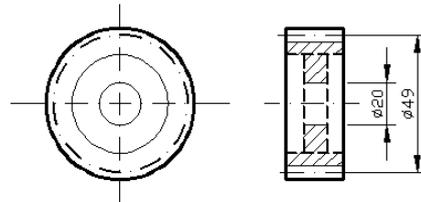


Figure 8. Gear

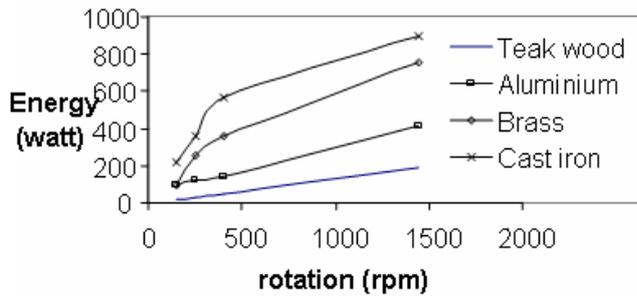


Figure 9. Diagram of energy requirement of gang drilling machine with materials and rotation variation

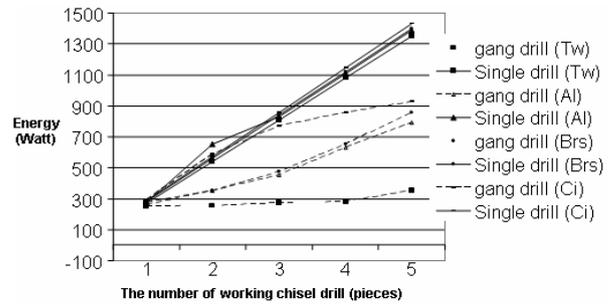


Figure 10. Diagram of comparison energy requirement of gangway machine drill with one motor and machine drill with one chisel (single drill)



Figure 11. Gang Drilling Machine [9]

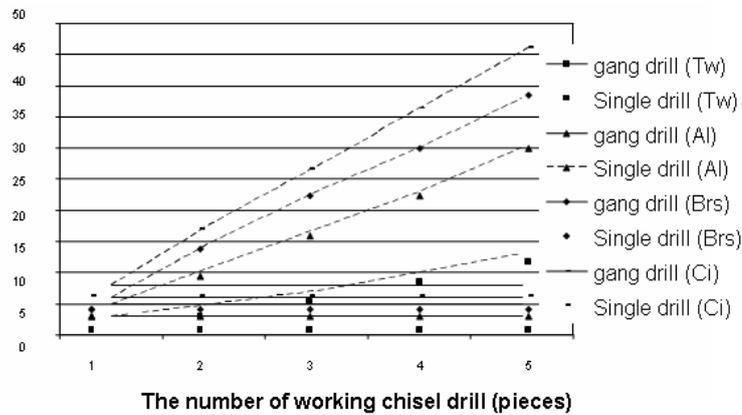


Figure 12. Diagram of comparative length of time drilling, drill machine with a gang drill machine with one motor and one chisel (single drill)

TABLE 1. MECHANICAL PROPERTIES OF MATERIAL TEST

Material Test	Tensile Stress		Elongation
	Tensile MPa	Yield Mpa	%
Teak	50	40	0%
Aluminium	70	20	60%
Brass	200	70	4%
Cast Iron	380	120	1%

TABLE 2. SHAFT SPECIFICATION

Material	Counter shaft	Shaft driven
	Carbon Steel AISI 1137	Carbon Steel AISI 1137

TABLE 3.
SPECIFICATION OF GEARS

	Pinion	Gear
Material	gear steel number 350	gear steel number 325
Diameter	36.75 mm	49 mm
Number of teeth	21 pieces	28 pieces
Width of teeth	24 mm	21 mm

TABLE 4.
BEARING SPECIFICATION

Type of bearing	Type of roller
Inside diameter (d)	20 mm
Outside diameter (D)	47 mm
Width	12 mm
Co	715 lb
C	1710 lb

TABLE 5.
PIN SPECIFICATION

Type of pin Material	Square standart key malleable iron grade 32510
Length (L)	0.8 in
Width (W)	0.25 in
High (H)	0.25 in

TABLE 6.
SRING SPESIFICATION

Spring material	ASTM class 20
Spring free length (Lf)	Malleable iron grade 32510
Inner diameter spring (D)	0.25 in
Outer diameter spring (Do)	0.25 in
Wire diameter (d)	0.8 in

TABLE 7.
ENERGY REQUIREMENT OF GANG DRILLING MACHINE WITH MATERIALS AND ROTATION VARIATION

Rotation	Teak wood (Tw)	Aluminium (Al)	Brass (Brs)	Cast iron (Ci)
150	15.6	90.8	95.1	212.8
250	26.5	122.0	259.0	355.2
400	43.6	144.4	355.7	569.7
1450	190.1	417.9	758.8	896.9

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