Assembly Modeling of a Mechanical Alarm Clock

Final Report

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1. Product Description

The product analyzed in this report is an Acu-Rite™ Alarm Clock (shown in Figure 1). More specifically, this alarm clock is a key wound bell alarm clock. Its main function include time wind-up, time setting, time indicating, alarm wind-up, alarm setting and ringing. This alarm has a brass case, white dial, self-luminous hands and hour markers. A separate alarm indicator is located on the dial as well. The clock is a fully mechanical clock. Thus no batteries are needed to keep it moving. The basic function of the clock is to indicate correct time and it is designed to wake up or remind a person at a specific time with ringing bells. To stop the alarm, a switch near the bell striker can be turned; it will also automatically stop the alarm if it is left unattended for long time. At the back of the clock, there are knobs to set the time and alarm, as well as wind up the clock and regulate the clock speed.

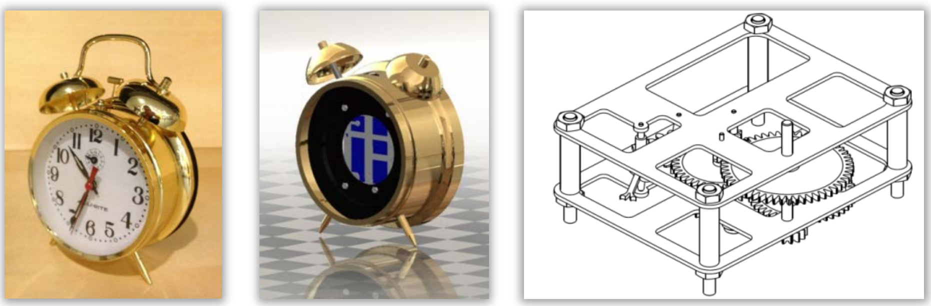

Figure 1 the real object and model of the clock

2. Disassembly Process and CAD Modeling

Figure 3 below illustrates the mechanical clock before disassembly. Figure 4 presents the final picture after disassembling every component in the mechanical clock.

Figure 2 views of clock before and during disassembly

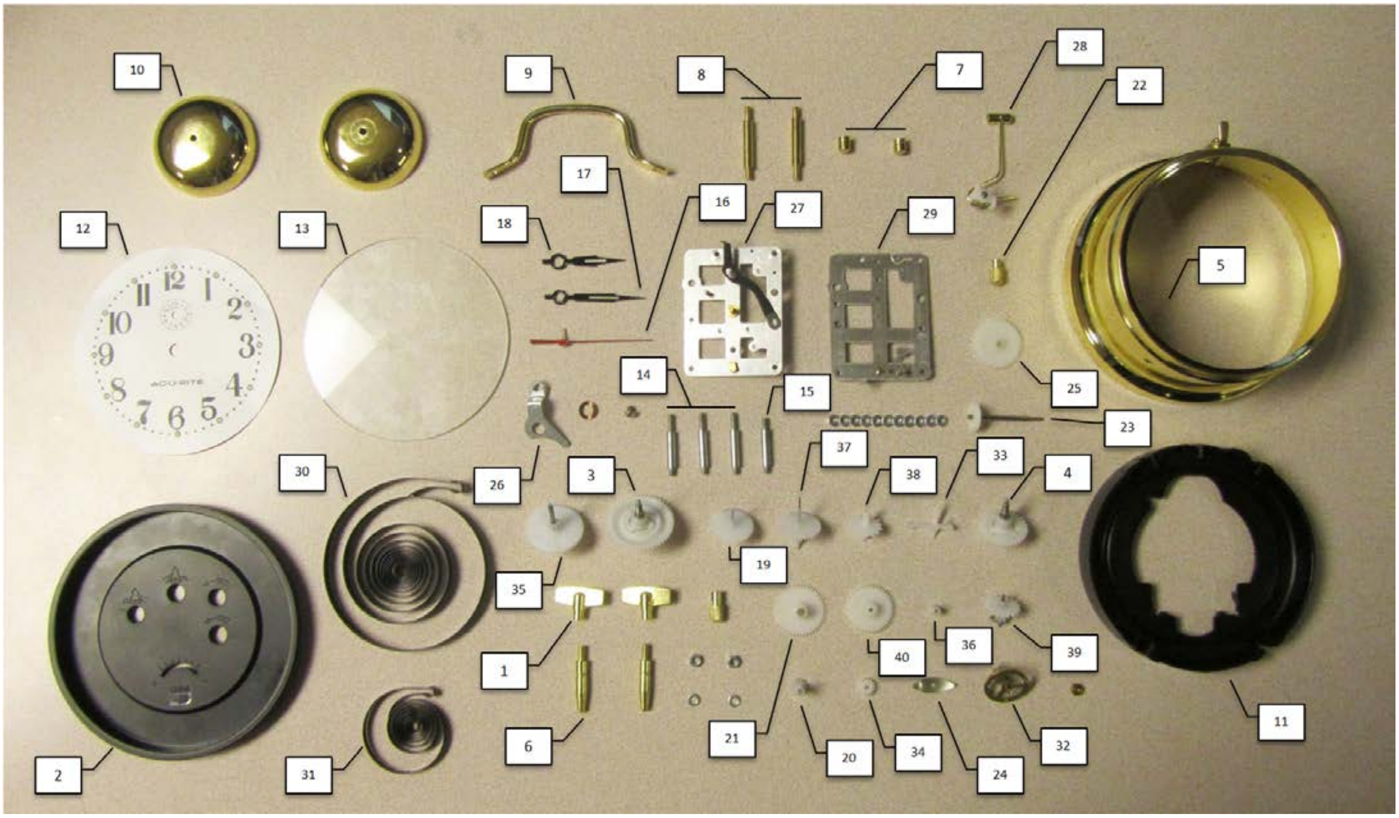

Figure 3 presentation of each component after disassembly

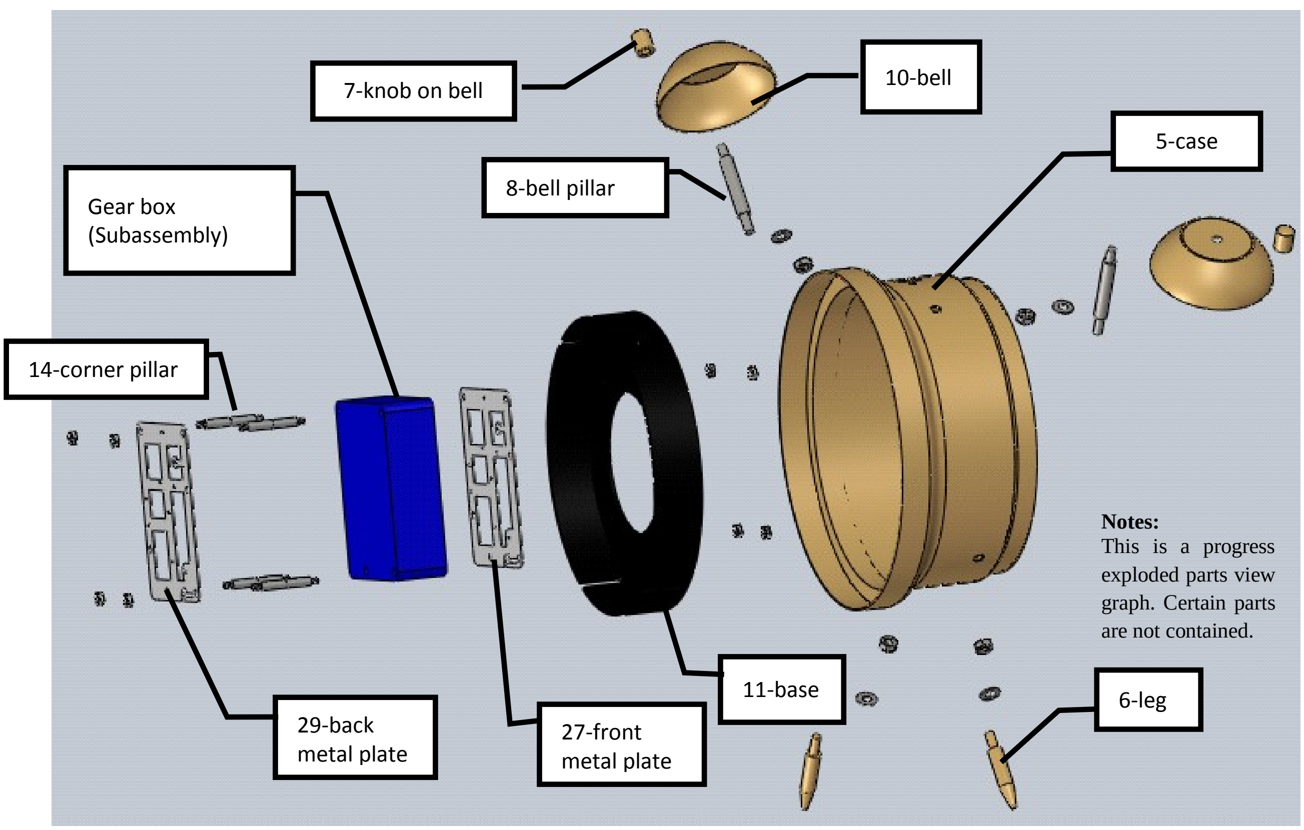

Figure 4 exploded view of the assembly drawing

In addition to the CAD model for the outer case, the clock core mechanism is also modeled. The offset section views of the core mechanism are presented below in Figure 6 & 7. Since the time keeping section is of more interest, only that part of gear chains are modeled to illustrate the transfer of rotary motion.

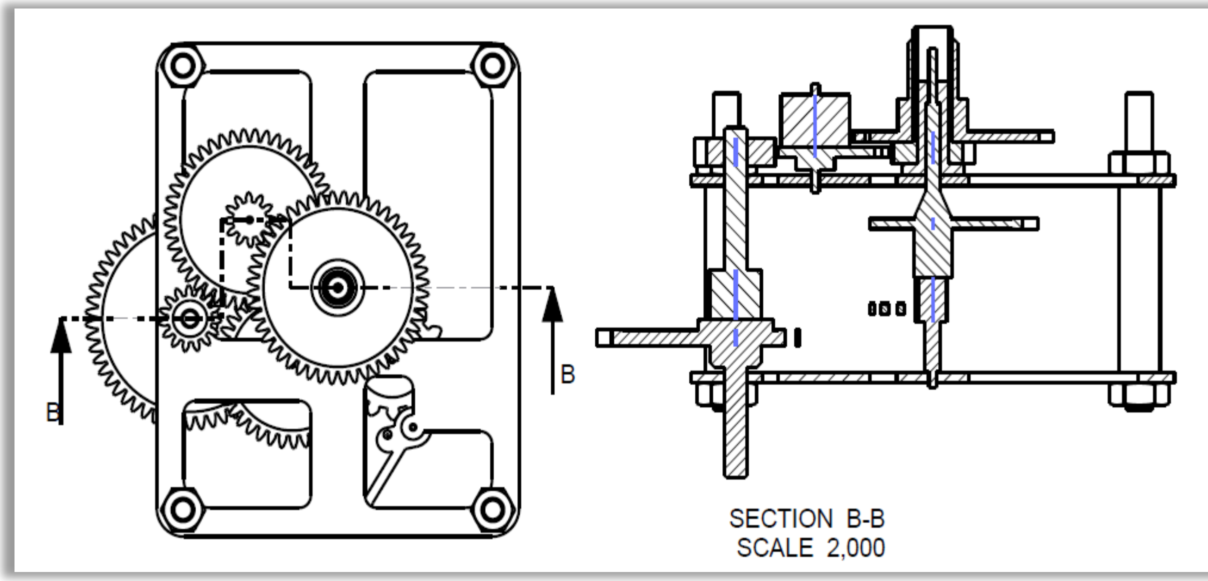

Figure 5 offset section view of the core mechanism (1)

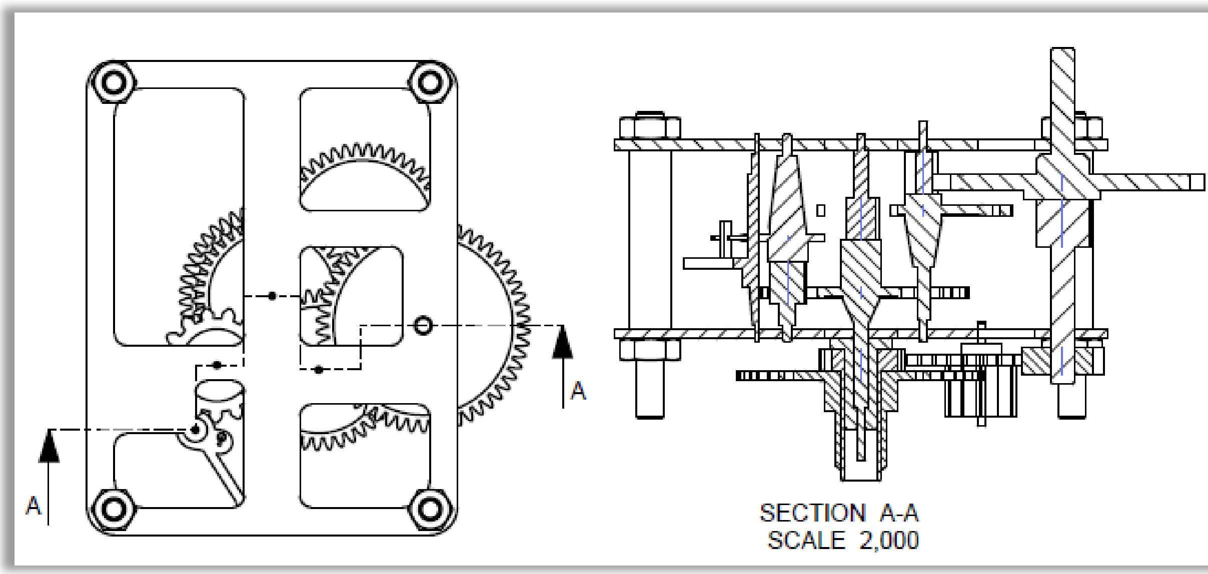

Figure 6 offset section view of the core mechanism (2)

3. Product Analysis

3.1 Bill of Materials (BOM)

Table 1 Bill of materials

#	Part name	Qty	Function	Material	Mfg process	Mate	Contact
1	T-shape handle	2	to wind up the related main string and provide power for clock or alarm	metal	stamping	3,4	
2	back plate	1	prevent dust enter the main mechanical part; indicate functions of each handle	ABS	Injection molding	5	
3	time mainspring gear	1	parts of the alarm mechanism	ABS	Injection molding	1,27,29,30,35	
4	alarm spring gear	1	parts of the alarm mechanism	ABS	Injection molding	1,27,29,15,31	
5	case	1	provide an aesthetic outlook; prevent dust enter the main mechanical parts	Steel	Stamping	6,8,13	
6	leg	2	support whole body of alarm clock	Steel	Turning	5,11	
7	knob on bell	2	fix twin bells	Steel	Stamping	8	
8	bell pillar	2	to connect bell to the case	Steel	Turning	5,7,10,11	9
9	bell connecting rod	1	to connect bell to the case	Steel	Turning		8,10
10	bell	2	make noise in a set time	Steel	Stamping	8	9
11	base	1	hold the whole inner mechanical part	ABS	Injection molding	6,8,12,13,14	29
12	clock panel	1	indicate time	paper	printing	11	
13	front cover	1	protect the clock face and provide a clear view of clock face	glass	cutting	5,11,12,14,15	
14	corner pillar(long)	3	to support two metal plate	Steel	Turning	11,27,29	
15	corner pillar(short)	1	to support two metal plate	Steel	Turning	27,29	
16	second hands	1	indicate exact seconds of time	ABS	Injection molding	19	
17	minute hands	1	indicate exact minutes of time	ABS	Injection molding	20	
18	hour hands	1	indicate exact hours of time	ABS	Injection molding	21	
19	second wheel	1	deliver motion to second hands	ABS	Injection molding	16,37,38	
20	minute wheel	1	deliver motion to minute hands	ABS	Injection molding	17,21,40	
21	hour wheel	1	deliver motion to hour hands	ABS	Injection molding	18,20,26,40	
22	round-shape handle	1	to adjust gear in order to change related position of clock or alarm hands	Brass	Turning	23	
23	alarm mechanism axle	1	deliver motion to adjust alarm	ABS	Injection molding	22,24,25,27,29	
24	leaf spring	1	provide spring power to reset the alarm mechanism position along axle	Steel	Stamping	29	
25	alarm mechanism gear	1	deliver motion to adjust alarm	ABS	Injection molding	23	
26	subassembly cover	1	constrain minute and hour gear to metal plate	Steel	Stamping	21,27	
27	front metal plate	1	locate the mechanical part	Steel	Stamping	3,4,14,15,23,24, 26,28,31,32,33,3 4,35,36,37,38,39	
28	bell striker	1	to strike the bell and make the noise	Steel	Stamping	27,29,39	
29	back metal plate	1	locate the mechanical part	Steel	Stamping	3,4,14,15,23,24, 26,28,31,32,33,3 4,35,36,37,38,39	11

30	mainspring (large spring)	1	provide power for the clock	Steel	Coiling	3,15	
31	alarm spring (small spring)	1	provide power for the alarm	Steel	Coiling	4,29	
32	oscillation wheel	1	oscillation wheel swings as a result they divide the time	Brass	stamping	27,29,33	
33	Swiss lever	1	1.escape wheel, pallet fork, oscillation spring and oscillation wheel form the ESCAPEMENT which controls the time of a clock 2.pallet fork and escape wheel control the power release according to the "divided time"	ABS	Injection molding	27,29,32,38	
34	time setting driving gear	1	provide driving force to adjust minute and hour hands position	ABS	Injection molding	27,29,35,40	
35	time setting gear	1	deliver motion to adjust minute and hour hands position	ABS	Injection molding	3,27,29,34,36,37	
36	bush	1	constrain z axis (along the axle) of time setting gear	ABS	Injection molding	27,29,35	
37	gear 1	1	connect second hand gear and time setting gear	ABS	Injection molding	27,29,35	
38	gear 2	1	deliver motion of Swiss lever	ABS	Injection molding	27,29,33	
39	gear 3	1	connect striker and alarm spring gear	ABS	Injection molding	4,27,28,29	
40	gear 4	1	connect time setting gear and minute and hour hand gear and	ABS	Injection molding	20,21,40	

3.2 Function Components

To be able to indicate time and set alarm, five functions need to be actively performed: time wind-up, time setting, alarm wind-up and alarm setting. Details regarding how each component helps the complete assembly deliver its function are shown on table1.

<u>Time wind-up</u>

The power of the whole timing mechanism comes from the mainspring located at the upper right corner in Figure 8. The power is obtained by turning time wind-up T-shape handle, which will connect to time mainspring gear, then deliver motion to the mainspring. To facilitate this, correct mating between handle and gear is required. If the gear is located incorrectly, the spring will not move and store power.

<u>Time indicating</u>

Power from the mainspring is receive by adjust gear and delivered to each hands gears. The oscillating wheel is connected to a Swiss lever (#33 in Figure.4) which is also directly connected to a gear that the second hand is mounted on. The Swiss lever acts like pendulum swinging back and forth, allowing gears to rotate one tooth at a time. The iconic sound “tick-tock” of a mechanical clock rightly comes from the movement of this Swiss lever. The rotation of the second hand gear is then transferred to an adjust gear. The adjust gear is so vital in the whole process that it receives power from the mainspring and delivers the movement of each second to the minute hand and hour hand gears. In addition, a user can directly adjust the time by turning the adjust gear. As the movement of the second hand gear is delivered to minute hand and hour hand gears, the importance of gear ratio begins to play a magic role. A typical clock dial is divided into 60 steps, designating 60 seconds in one minute. The minute hand advances one step when the second hand moves 60 steps. The hour hand advances 5 steps while the minute hand completes 60 steps. Thus the overall gear ratio from the second hand gear to the hour hand gear is set as 720:12:1. In order to minimize the size of overall gear trains, most gears are made into concentric gears. The movement of second hand gear is hence transferred to the minute hand and hour hand gears through delicately tuned gear ratios, so that each hand can rotate concentrically at the correct speed (shown in Figure 8).

<u>Time setting</u>
Time setting is achieved by turning the round shape handle to move the adjust gear, which will drive motion to minute and hour hands gear, thus change position of the hands.

<u>Alarm wind-up</u>
Similar to time wind-up, the small mainspring on the left powers the alarm mechanism. The power of alarm spring is obtained by turning alarm wind-up T-shape handle, which motion will be delivered through the attached axles of gears, and then connect to time mainspring gear, thus deliver motion to the mainspring so that their stored potential energy can be converted to kinematic energy. Escapements are used here to control the unwinding speed of the mainsprings, preventing them from releasing the potential energy too fast.

<u>Alarm setting and ringing</u>
The alarm time is set by turning the alarm setting round-shape handle. Regarding the alarming mechanism, the small mainspring does not move all the time. Instead, it remains wound up and ready for release until a set alarm time is reached. When that time comes, a cantilever is pushed down making it no longer constrain the movement of the alarm bell striker. With the quick unwinding of the mainspring, the striker is pushed back and forth via a reverse Swiss lever, vibrating a pair of bells to produce the alarm noise.

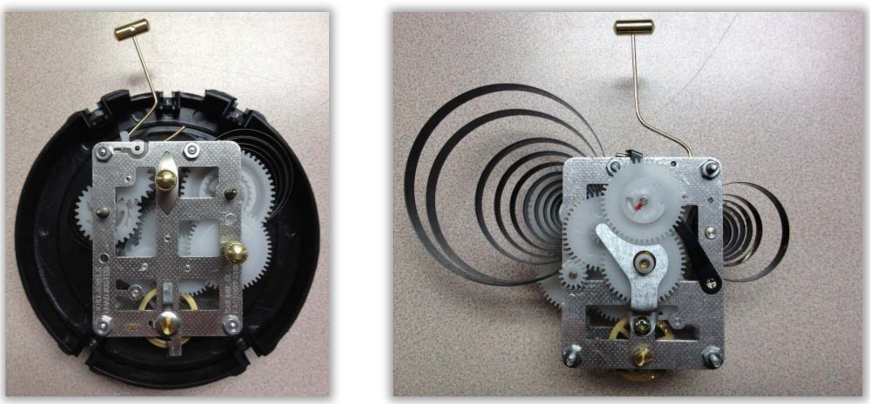

Figure 7 detailed view of the whole clock movement

3.3 List of Clearance Ratios and Assembly Difficulties

Table 2 List of clearance ratios

#	Clearance	Measured Values						Average	Clearance	Ratio
1	base locating							n, m	C=(m-n)	R=C/m
	OD base	113.74	113.50	113.64	113.72	113.60	113.50	113.62	-0.136667	-0.00120
	ID case	113.42	113.52	113.62	113.38	113.44	113.50	113.48		

2	back plate locating									
	OD back plate	101.20	101.18	101.16	101.22	101.18	101.22	101.193	-0.076667	-0.00076
	ID case	101.14	101.20	101.08	101.12	101.06	101.10	101.12		
3	leg locating									
	OD leg	3.08	2.98	3.00	3.06	3.02	3.00	3.02333	0.1866667	0.058152
	ID hole	3.22	3.28	3.24	3.18	3.14	3.20	3.21		
4	gear axle to hole									
	OD gear axle	0.86	0.82	0.78	0.84	0.80	0.82	0.82	0.0033333	0.004049
	ID hole in metal plate	0.80	0.84	0.82	0.86	0.80	0.82	0.82333		
5	gear axle to hole									
	OD gear axle	0.84	0.82	0.84	0.78	0.86	0.86	0.83333	0.0066667	0.007937
	ID hole in metal plate	0.86	0.80	0.86	0.86	0.84	0.82	0.84		
6	gear axle to hole									
	OD gear axle	0.80	0.82	0.86	0.84	0.88	0.86	0.84333	0.0033333	0.003937
	ID hole in metal plate	0.88	0.84	0.86	0.86	0.84	0.80	0.84667		
7	gear axle to hole									
	OD gear axle	0.80	0.86	0.84	0.82	0.80	0.84	0.82667	0.0066667	0.008
	ID hole in metal plate	0.80	0.84	0.86	0.80	0.84	0.86	0.83333		
8	gear axle to hole									
	OD gear axle	0.80	0.82	0.84	0.86	0.82	0.86	0.83333	0.0033333	0.003984
	ID hole in metal plate	0.86	0.84	0.86	0.80	0.82	0.84	0.83667		
9	gear axle to hole									
	OD gear axle	0.86	0.80	0.84	0.82	0.86	0.80	0.83	0.0133333	0.01581
	ID hole in metal plate	0.84	0.86	0.84	0.82	0.86	0.84	0.84333		
10	gear axle to hole									
	OD gear axle	0.82	0.80	0.84	0.8	0.82	0.84	0.82	0.0033333	0.004049
	ID hole in metal plate	0.80	0.82	0.86	0.8	0.84	0.82	0.82333		
11	gear axle to hole									
	OD gear axle	1.44	1.42	1.40	1.42	1.46	1.40	1.42333	0.0133333	0.009281
	ID hole in metal plate	1.42	1.40	1.48	1.46	1.44	1.42	1.43667		
12	gear axle to hole									
	OD gear axle	0.88	0.82	0.84	0.82	0.88	0.86	0.85	0.0033333	0.003906
	ID hole in metal plate	0.86	0.84	0.86	0.86	0.86	0.84	0.85333		

The clearance ratios on this product illustrate the precision of component manufacture. Measurements were taken six times for each feature and averaged to find the most accurate values possible and minimize error.

The location of back-plate or base to clock case (#1 and #2), had negative clearance ratios. This indicates a Press Fit, or Interference Fit. Upon closer observation, this is correct because those two features provide enough friction from their press fit to hold themselves to the case together (feature six) and seat to body (feature twelve) while waiting for fasteners to be added. This is an intentional assembly aid to prevent the parts from separating.

The clearance of gear axles and metal plate are all greater than zero. This makes sense functionally as the axles require degree of freedom in order to rotate and support engaging gears. Also, the dimensions of axles and holes on metal plate are so small that the increasing of clearance is preferable for the assembly operation.

When assembling, all the 6 axles of the gears already set on the back plate should be aligned with holes on the front plate, which is very difficult. Because axles are under-constrained, additional fixtures should be utilized to help achieve alignment. In addition, the spring of oscillating wheel is so delicate that if not carefully handled by hand, deformation will be caused. And because the bell striker is assembled after the assembly between the back and front plates, it should also be assembled by hand.

4. Datum Flow Chain analysis

4.1 Liaison Diagram

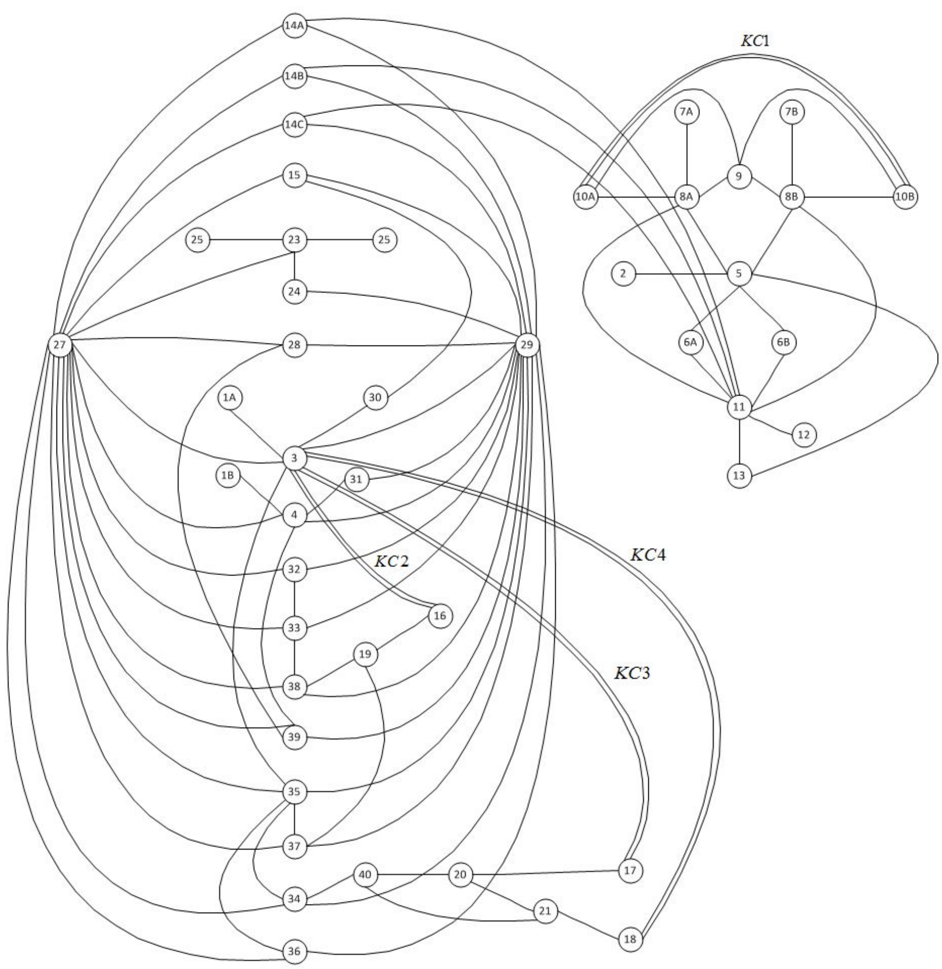

Figure 8 Liaison Diagram

4.2 Key Characteristic (KC) Analysis

The alarm clock has two main functions. One is to indicate time and another is to alarm. The key characteristics are derived from these two main functions. We determined that the alarm bells should be at the right position so that they can be assembled to the clock and be hit by the bell striker. Moreover, the angular position of the hands of the clock should be precisely determined by the main gear which is powered by the mainspring. The KCs to deliver the functions and the Datum Flow Chain (DFC) analysis are listed in the table below.

Table 3 Key characteristics of the alarm clock with relation to product function and datum flow chain

KC number	Description	Relation to Product Function	Datum Flow Chain (DFC)	KC conflict
1	X, Y, Z dimension from left bell to right bell	Alarm	10B->8B->5->8A->10A	No
2	Θz position difference between the main gear and the second hand	Indicate time	3->35->37->19->16	Yes
3	Θz position difference between the main gear and the minute hand	Indicate time	3->35->34->40->20->17	Yes
4	Θz position difference between the main gear and the hour hand	Indicate time	3->35->34->40->21->18	Yes

KC1: distance from one bell to the other bell in the X, Y, Z dimension
This dimension is key characteristic because that ensuring the KC will enables the bell striker to hit both bells on the left and right sides and enable the bell connecting rod to connect both bells. In this way, the alarm clock is able to wake a person or work as a reminder as a specific time.

From table 3, the KC delivery chain for X, Y, and Z dimension involves 5 components, they are the two bells on left and right sides, two bell pillar that support the bells, and the main case. Since is no other KCs that share this delivery chain, there is no KC conflict.

KC2: Θz position difference between the main gear and the second hand
This KC is important since it ensures that the second hand rotates precisely synchronize with the main gear, which rotate a certain angle every second. Achieving this KC makes the second hand to move a step forward every second and enables it to indicate time in second on the clock panel.

From table 3, the KC delivery chain for the Θz position involves 5 components. They are the main gear, gears numbered as 35, 37, then the second wheel and finally the second hand. As this KC share directed edge 3->35 with KC3 and KC4, it will have a KC conflict. But as the minute hand advances 1 step as second hand advances precisely 60 steps, the hour hand advances 1 step as the minute hand advances 5 steps. Therefore, the KC conflict will not cause a problem.

KC3: Θz position difference between the main gear and the minute hand

This KC is important since it ensures that the minute hand advances precisely according to the main gear, which advances every second. Achieving this KC makes the minute hand to move a step forward every minute and enables it to indicate time in minute on the clock panel.

From table 3, the KC delivery chain for the Θz position involves 6 components. They are the main gear, gears numbered 35, and its coaxial gear numbered 34, gear numbered 40 then the minute wheel and finally the minute hand. As this KC share directed edge 3->35 with KC2, and share directed edge 3->35->34->40 with KC4, it will have a KC conflict. But as the minute hand advances 1 step as second hand advances precisely 60 steps, the hour hand advances 1 step as the minute hand advances 5 steps. Therefore, the KC conflict will not cause a problem.

KC4: Θz position difference between the main gear and the hour hand

This angular position relationship is a KC because it ensures the hour hand to advance precisely according to the main gear. Achieving this KC enables the hour hand to advance a step forward every hour and enables it to indicate time in hour on the clock panel.

From table 3, the KC delivery chain for the Θz position involves 6 components, including main gear, gears numbered as 35, and its coaxial gear numbered 34, gear numbered 40 and then the hour wheel and finally the hour hand. This KC share directed edge 3->35 with KC2, and share directed edge 3->35->34->40 with KC3, it will have a KC conflict. But as the minute hand advances precisely 12 times faster than the hour hand, and the second hand advances precisely 60 times faster than the hour hand, it will not cause a problem.

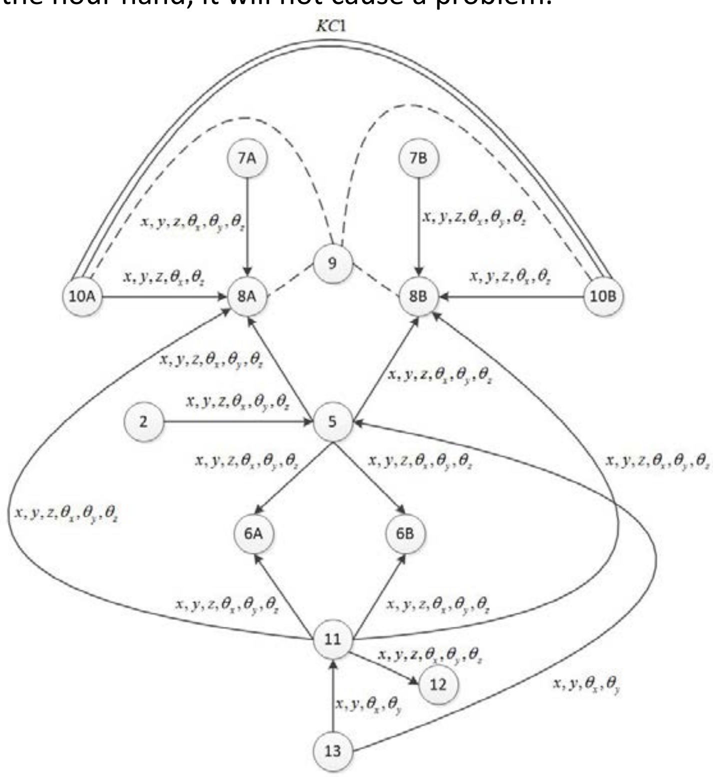

Figure 9 Datum Flow Chain for KC1

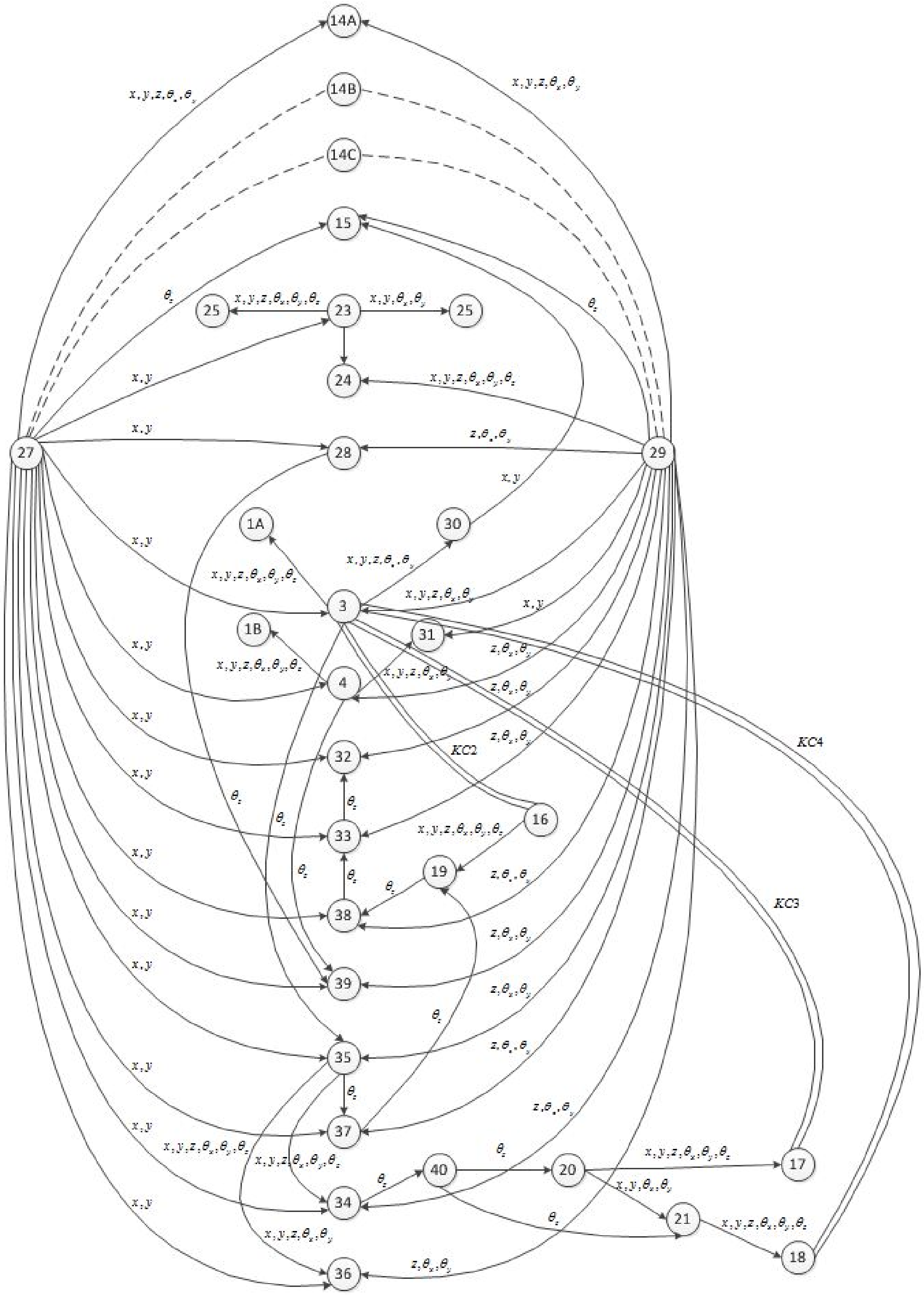

Figure 10 Datum Flow Chain for KC2, KC3, KC4

4.3 Datum Flow Chain (DFC) Explanation

The main case of the alarm clock has four holes on it, which is designed to mate with the peg on the clock leg and bell pillar. They are then constrained with nuts. There are pegs on the other side of the bell pillar which inserts to the holes on the bells and they are constrained with nuts. One KC is the distance between two bells, since achieving this will enable the striker to move back and forth to hit both bells. The KC delivery chain can be found in the DFC in figure 10, which is 10B->8B->5->8A->10A. The gear box of the clock, which is the main subassembly of the alarm clock, is made by sandwiching gears with the front metal plate and the back metal plate. There are holes for gear axes and support pillars on the front and back metal plate. The two plates are mated with two pillars, and constrained with two other pillars and nuts. There are 3 KCs in the gear box. They are the angular position relationship between the main gear and the second hand, the minute hand, and the hour hand. The KC delivery chains are 3->35->37->19->16, 3->35->34->40->20->17, and 3->35->34->40->21->18 respectively in figure 11. Achieving these three KCs will enable the alarm clock to indicate time precisely.

The most important subassembly of the alarm clock is the gear box. The datum flow chain (DFC) is presented in figure 11. The front metal plate and the back metal plate are connected with four corner pillars. Two of the pillars, which are numbered 14A and 15, mate the front and the back metal plates. The pillar 14A locates the X, Y, Z position of the back and front plates, the pillar 15 ensure the two plates won't be able to rotate about the z axis. The other two pillars further support the back and front metal plates. As there are four pillars support the metal plates together, there is risk of over constraints in X, Y, and Z direction. There are holes on the both the front and back plates. The two ends of axis of each gear are put into the holes on the front and back plates, the X, Y, Z position of the gears are located by the front and back plates and the gears cannot rotate in the ϴX and ϴY direction. Only one degree of freedom, which is the rotation about Z axis, is left for each gear. This way each gear is well constrained on both sides and can rotate about Z axis. The gears are meshed together one by one to meet the required angular speed output of the second wheel, minute hand, and hour hand. Therefore, starting from the main gear, which is powered by the mainspring, each gear constrains the rotate in ϴZ direction of the gears meshed with it. Therefore, all the gears are well constrained.

4.4 Redesigns Suggestions

For KC1, there are five components to deliver the KC. Our suggestion is that the bell pillar can be design as a feature of the main case, this way two components are saved. As there are fewer components, there will be less error delivered because of assembly. There are also other alarm clock designs that have the case work as bells. This save two more components and may cause less error.

For KC2, KC3, KC4, even though there are KC conflicts, but this design helps to make the mechanism compact and can enable the send hand, minute hand, hour hand to work precisely at the required speed. Therefore, the current KC deliveries of KC2, KC3, and KC4 cannot be improved.

5. Assembly Sequence Analysis

5.1 Assembly Sequence Generation

We got the knowledge of practical assembly sequence from the experience of disassembly. Afterwards, we reversely assembled the clock and verified that this sequence is most realistic.

The 2 successive figures, Figure 12 and Figure 13 shown below revealed the assembly sequence recommended by us. It was established based on:

(1) Precedence constraints (e.g., without assembly of 2, the back plate, we cannot assembly 1A and 1B , which are T-shape handles outside the back plate);
(2) For the convenience of fixtures (e.g. we should firstly assembly all the gears on 29, the back metal plate, then use fixture to mate 27, the back metal plate to it, rather than use 27 as the initial base, because the flatter backside of 29 makes it easier than 27 to incorporate with a fixture);
(3) Protection of fragile components (e.g., the oscillator, named 32, is assembled after 27 has been mated with 29, rather than being assembled on 29 before 27 is mated, because the little pin of 32 can be easily damaged in the latter way);
(4) Grouping of components and tools for the convenience of work element balance.

Note that in the figures below, each box represents either a subassembly or a component; numbers combined with capital letters represents different individual components which are of the same type (e.g., 1A is a T-shape handle, while 1B is another one. Both of them belong to the same type of components – T-shape handles). Let us use one example to explain the meaning of ellipsis: the ellipsis in "-14B-14C-15-16-17-…-38-39-40", located inside the top box, means that components numbered after 17 and 38 only possess a single individual part, that is to say, labels like 18C or 19A do not exist.

Firstly, the worker could assemble gears and main springs (39, 38, 37, 19, 35 combined with 36, 33, 4 combined with 31, 3 combined with 30) on the back metal plate 29, then 27 would be assembled to subassembly containing 29. Thus the key part of this clock have been accomplished, we call this assembly Sub_Key for short. All these work can be accomplished within one work station with one worker.

Successively, another woker could assemble the oscillator 32, the bell striker 28, and the mechanism for velocity control (40, 21, 20) to Sub_key, and assemble subassembly cover 26 to keep all the mechanism. Furthermore, the alarm mechanism (24 and SUB_2: 23-25) is also assembled to Sub_Key. This is the work element in the 2nd work station.

Before the 3rd worker receive the subassembly from the former station, he/she can assemble the case 5 to the front cover 13, which form the SUB_1 in Figure 12 below. When he/she have received the subassembly from the upstream, the worker could assemble hands (16, 17, 18) and the clock face, and wind the nob of main springs and fit the total subassembly we have just accomplished to the case. Let us call this new sub-assembly Sub_K2 for short. Then the worker can fit Sub_K2 into SUB_1 (5-13, as indicated in the diagram below).

The remaining work is only to assemble components related to the bells (7,8,9,10), leg and the back plate. These works could be done by a forth station with another worker.

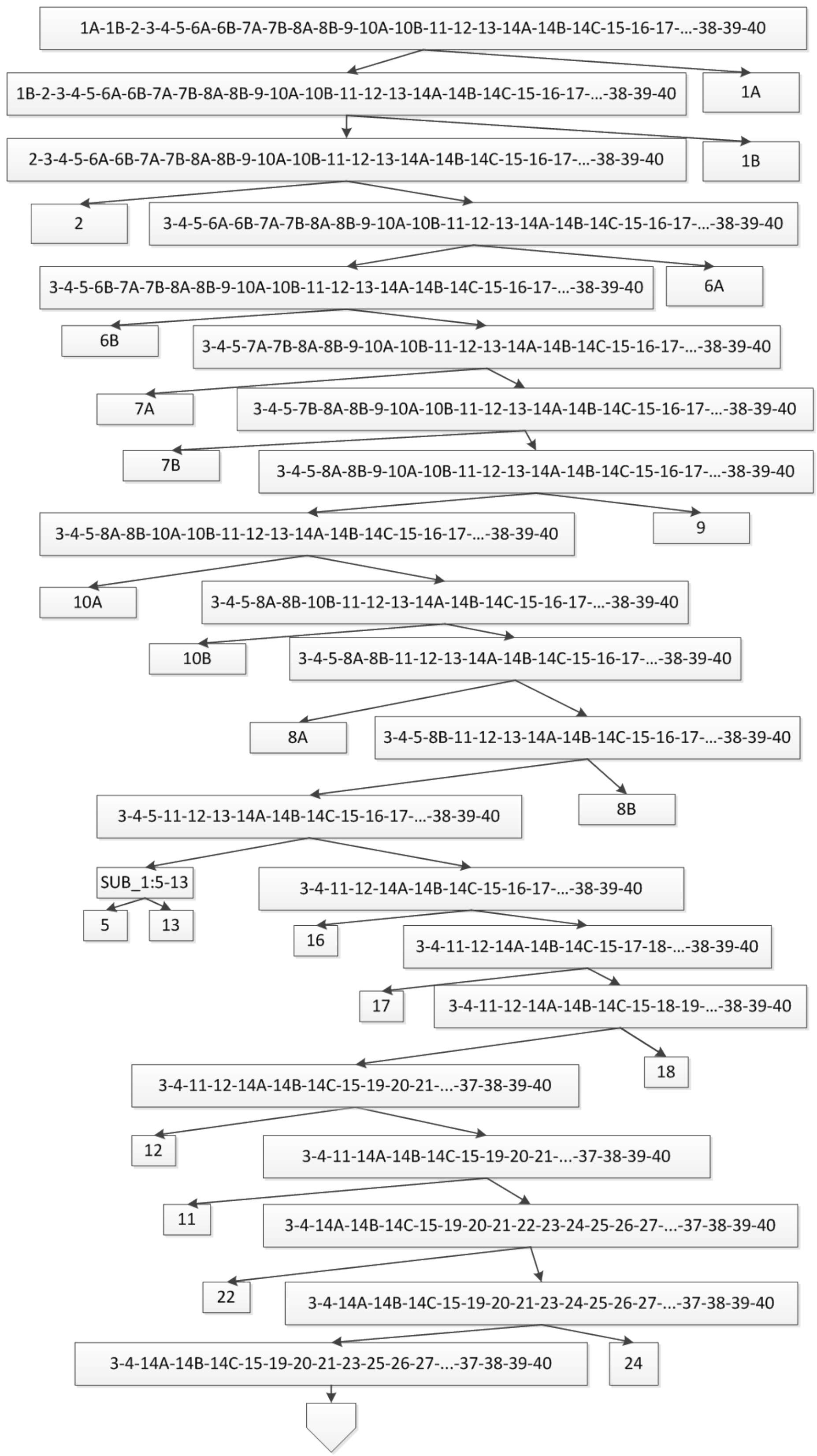

Figure 11 Part 1 of the assembly sequence diagram

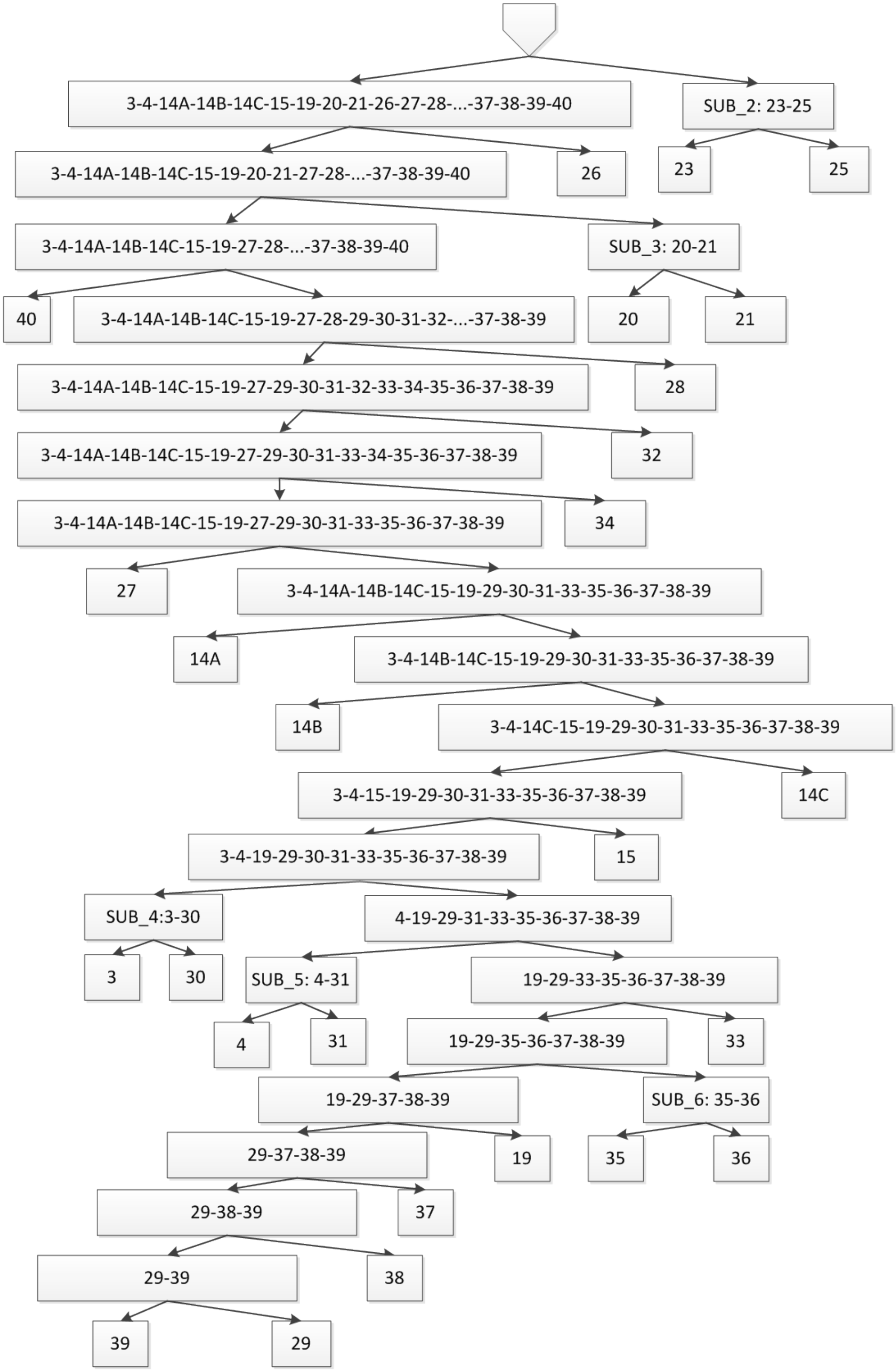

Figure 12 Part 2 of the assembly sequence diagram

5.2 Motion Analysis

Fine & Gross analysis, combined with reorientation analysis and practical use of fixtures are listed in Table 4. Note that names like “SUB_1”, “SUB_2” , “SUB_3” , “SUB_4” , “SUB_5” and “SUB_6” has been displayed in the diagram above, while “Sub_Key” and “Sub_K2” just follow the description in above “Assembly Sequence Analysis”.

Furthermore, we simplified the assembly sequence in Table 4 in two ways. Firstly, we use ellipses in the Column “Assembled to” merely to save the space, which does not follow the description of the ellipsis above in the Assembly Sequence Analysis. So the readers have to refer to the diagram when they don’t know what the subassemblies containing ellipses represent.

Secondly, some assembly procedures are combined. For example, 39, 38, 37, SUB_6, 19, 33, SUB_5, SUB_4, 15, 14A, 14B, 14C are sequentially assembled in the diagram, but in the table, we say that those components are assembled to front plate metal 29 because it is actually the case and when assembling, the impact between those components is quite small and these assembly motion are quite similar.

Table 4 Motion analysis of mechanical clock

Component	Assembled to	Motion	Reorient.	Assumptions
36	35	Fine	No	35 is held by hand
31	4	Fine	No	4 is held by hand
30	3	Fine	No	3 is held by hand
39,38,37,SUB_6,19,33,SUB_5,SUB_4,15,14A,14B,14C	29	Gross	No	29 is constrained by a fixture
27	3-4-14A-…-39	Gross	No	fix the "assembled to" sub-assembly
34	3-4-…-27-…-39	Fine	No	fix the "assembled to" sub-assembly
32	3-4-…-34-…-39	Gross	No	fix the "assembled to" sub-assembly
28	3-4-…-32-…-39	Gross	No	fix the "assembled to" sub-assembly
20	21	Fine	No	21 is held uprightly by hand
40	3-4-…28-…-39	Fine	No	fix the "assembled to" sub-assembly
SUB_3	3-4-…-39-40	Gross	No	fix the "assembled to" sub-assembly
25	23	Fine	No	23 is held uprightly by hand
26	3-4-…-20-…-40	Fine	No	fix the "assembled to" sub-assembly
SUB_2	3-4-…-26-…-40	Gross	No	fix the "assembled to" sub-assembly
24	3-4-…-23-…-40	Gross	Yes	fix the "assembled to" sub-assembly
22	3-4-…-24-…-40	Fine	No	fix the "assembled to" sub-assembly
11	3-4-…-22-…-40	Gross	Yes	fix the "assembled to" sub-assembly
12	3-4-11-…-40	Gross	No	hold "assembled to" sub-assembly by hand

18	3-…-12-…-40	Fine	No	hold "assembled to" sub-assembly by hand
17	3-…-18-…-40	Fine	No	hold "assembled to" sub-assembly by hand
16	3-…-17-…-40	Fine	No	hold "assembled to" sub-assembly by hand
13	5	Fine	No	13 is held uprightly by hand
3-…-16-…-40	SUB_1	Gross	Yes	5 is held horizontally by hand
8B	3-…-13-…-40	Fine	No	5 is held horizontally by hand
8A	3-…-8B-…-40	Fine	No	5 is held horizontally by hand
10B	3-…-8A-…-40	Fine	No	5 is held horizontally by hand
10A	3-…-10B-…-40	Fine	No	5 is held horizontally by hand
9	3-…-10A-…-40	Fine	No	5 is held horizontally by hand
7B	3-…-9-…-40	Fine	No	5 is held horizontally by hand
7A	3-…-7B-…-40	Fine	No	5 is held horizontally by hand
6B	3-…-7A-…-40	Fine	No	5 is held horizontally by hand
6A	3-…-6B-…-40	Fine	No	5 is held horizontally by hand
2	3-…-6A-…-40	Fine	No	5 is held horizontally by hand
1B	2-3-…-40	Fine	No	5 is held horizontally by hand
1A	1B-2-…-40	Fine	No	5 is held horizontally by hand

5.3 Assembly Aiding Features

According to the sequence analysis diagram, parts can be analyzed and placed where they belong to. There are specially designed features in the parts which can facilitate the assembly process. These features include places where can be gripped or mated to a fixture, or chamfers to help the lead-in process. The upper (part 27) and bottom (part 29) plates of the clock core is supported by four pillars (part 14) in corners (as shown in Figure 14). The pillars on one hand support the whole structure, while on the other hand act as handles which can be easily gripped on while transporting the assembly from one station to another.

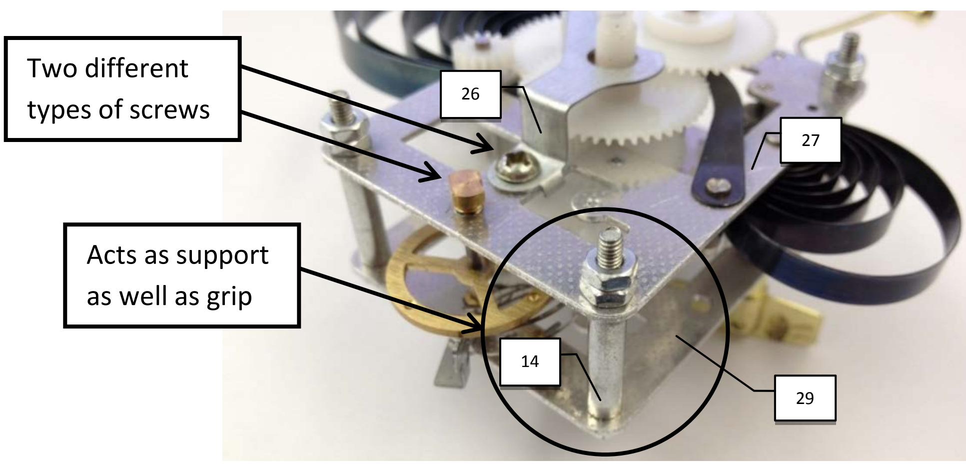

Figure 14 Corner pillars between the upper and bottom plates

When enclosing various gears into the space between the upper and bottom plates, the bottom plate (part 29) is positioned on a fixture to facilitate the process. From Figure 15 below, it can be seen that there are two threaded holes without any components in them. It is believed that these holes enable the part to be mated to an external fixture, so that the position of the bottom plate can be secured.

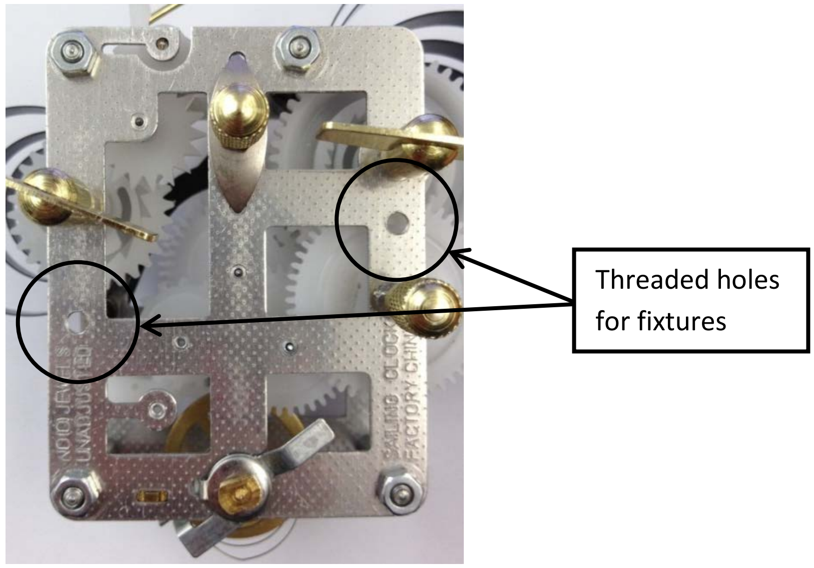

Figure 15 Two threaded holes on the bottom plate (part 29)

Since gears are extensively used in the clock core mechanism, pin and hole mating is quite popular throughout the whole design. In order to ensure accurate mating, chamfers are added to both ends of each gear axle to assist the leading-in of gears. Namely gears NO. 3, 4, 19, 33, 35, 37, 38, 39 which are placed between the upper and bottom plates are treated this way. In addition, some other rotary components are also chamfered to ease their assembly, such as the bell striker (part 28) and the oscillation wheel (part 32). Some examples of chamfered ends of part 3, 4 and 23 are illustrated in the following Figure 16.

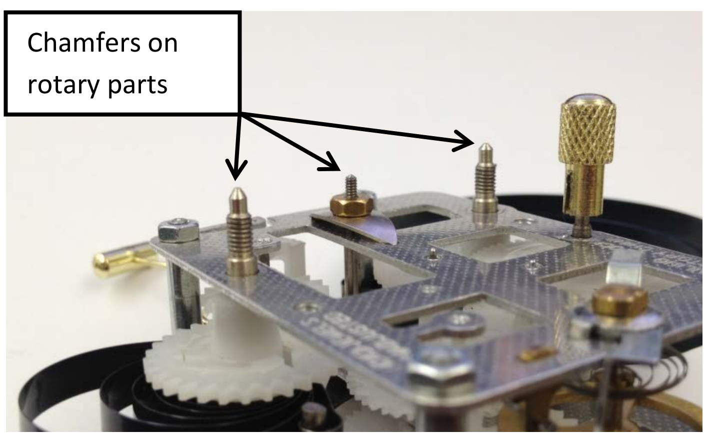

Figure 16 Chamfer features on the core assembly

Two types of fasteners are used in this assembly: stud and nut, and screw. In the core assembly, four studs are used in four corners to support the whole structure and secure the positions of gears in between. Three of them are in the same lengths, while the other one is slightly shorter to provide enough space for the alarm mechanism. In the outer case assembly, two studs are used to fix the bells and the two legs are pre-threaded. Since all threads have the same nominal diameter of 1.5mm, all the nuts used here have the same dimension. Totally fifteen nuts are used in the assembly. Two of them fix the bell studs and two are used to mount the legs. Eight of them fasten the upper and bottom plates (one pair for each stud). The other three nuts are allocated for the longer studs to fix the core assembly onto the front panel plate (part 11). Two different screws are used in the core assembly (shown in Figure 14). The copper screw is for adjusting the rotary friction of the oscillation wheel (part 32), which can affect the ticking speed of the clock. The steel screw is for fastening the subassembly cover (part 26) onto the upper plate (part 27) such that the vertical movements of minute and hour hand gears are constrained.

Certain auxiliary operations need to be done after the assembly. Firstly, lubricant should be added to the gear axles through the holes on the upper (part 27) and bottom (part 29) plates. Secondly, all gears should be inspected and tested if they can pass the rotary motion from one to another. Thirdly, the Swiss lever (part 33) and oscillation wheel (part 32) should be tuned to make sure the clock is punctual.

5.4 Possible Assembly Problems and Improvements

This clock core assembly is a highly precise mechanism which is usually assembled by hands. The most challenging part of the assembly is to accurately place each gear in their locations at once. It is quite difficult to achieve this outcome without introducing any fixture; because before the upper plate is (part 27) is placed on, gears are hardly stable standing on their axles. Thus at least two fixtures are required in order to hold the bottom plate (part 29) and the gears. Once the bottom plate is fixed, gears can be carefully placed in the desired order. Then with the help of other fixtures, the positions of gears become definite. Figure 17 below shows one possible solution by adding on three magnetic fixtures to fix the positions of those gears. Because the gear axles are made out of steel, using magnetic fixtures would be an efficient approach. At last, the upper plate can be easily put on with all gears in position. In addition, when dealing with small parts, using a pair of tweezers would be convenient for the workers.

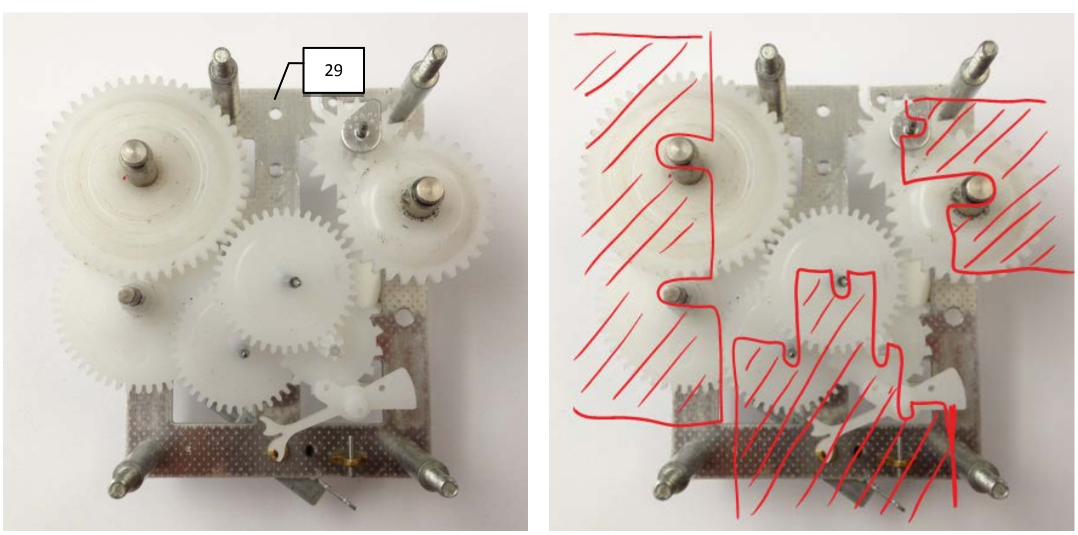

Figure 17 Possible fixtures added on before assembling the upper plate

As can be seen in the above pictures, gears are manufactured from ABS plastic except for their axles. From the manufacturer's point of view, the main reason of using plastic is to reduce the costs. However, ABS plastic is less durable than its common alternative – brass in this application. This low durability might cause damage on parts during handling and wear during clock operating. The solution to this problem is to simply manufacture all moving parts using brass, which inevitably increases the cost of the clock. Hence, a trade-off must be made when selecting suitable materials for those gear components.

Another improvement can be made on the product design is on the KC deliver chain. Currently KC2 is sharing "chain 3->35" with KC3 and KC4. KC3 is sharing "chain 3->35->34->40" with KC4. In this specific design, there is a reason why those KC conflicts exist. As mentioned above, the ratio of rotating speed of the second hand to minute hand to hour hand is 720:12:1. In order to achieve this exact ratio, those three output gears must share the same gear chain. Despite the fact that if one gear in this chain rotates slower, the whole clock will run slower, the position of those hands on the clock dial will never be wrong. But this does not mean there is no way to improve the clock accuracy. One approach can be done is to manufacture parts 3, 34, 35 and 40 from brass in order to reduce the part variations, which minimize the effect of variations stack-up.

6. References

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