Slim Size Card Key Development

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Abstract— **Key being used to identify & allow door access and engine start has been developed to the possibility of integration into the cellular phone with the help of increased electronics and wireless communication skill. But even all electrical function can replace conventional ones, it still need mechanical key blade for the case of emergency situation. From that view, card type key would be more widely used in the future in the market due to the existence of emergency key blade. Making all required function work in slim size thickness is important success criteria for more widely use by increasing convenience of customer in carrying in the wallet.**

To overcome height limitation, integrated circuit type with a PLL IC/MCU, PCB coil antenna with thin battery was applied. Assessment of the various production methodology was done and RTM (resin transfer molding) method was selected. To make around 3mm thickness card type key, other conventional way that have been used up to now was not appropriate to overcome the constraints of the product to meet the functional requirement.

This study shows main factors to be considered in product development of card type key for the case of RTM(Resin Transfer Molding) application and also important test result required for product development verification & validation. To fix complicated mold parameter for best condition, DOE (Design of Experiment) method was applied to reduce repetitive back& forth efforts. Making thickness be reduced from above 6 mm to 3 mm thickness level was possible by applying RTM method and this development result shows the possibility of making more slim cardkey in case challenged more.

Keywords-Card Key; Resin Transfer Molding

I. INTRODUCTION

In Auto industry, conventional Key that enables engine start and access into the car had been long time mechanical key that only work by doing insertion of the key blade into the key slot and rotation manually. But nowadays more electronics became integrated into the car and that made possible to replace mechanical components into more electronics products. Furthermore enhanced wireless communication function also make possible to reflect user's intention at much convenient status even from long distance.

It became common technology to let engine start or make users access into inside of the car without mechanical key or without pushing any button such as a lock, unlock button of the key by doing personal ID confirmation via wireless communication.

In current car access & engine start systems, keys are doing important role as an ID confirmation. When users approach near the door with key, by just pushing the button on the door handle or just by touching the sensor of the door handle, LF signal from car is sent to key and then it return RF signal to the car for ID confirmation. The same LF&RF communication way is working for engine start. Once start button of engine is pushed, same ID confirmation process is working for engine start.

Mechanical key blade is being used only for the emergency situation when electrical function of key is not working so access inside the car is only possible by using emergency key blade. Emergency engine start is only possible by using transponder communication between key & start button. So nowadays, most of the conventional mechanical key functions are replaced by the electrical functions, the only thing left is the emergency key blade that allows door access in electrical malfunction situation.

With the development of cellular phone technology industry, to enable bi-directional communication between car and users, keys are expected to be integrated to the cellular phone. But still for the case of mal-functioning of key system, we need emergency key that works for both electrical function and mechanical key blade. From that view, portable slim size card-key would be demanded more in the future as a solution for that.

Now high-end vehicles, card keys are being used in addition to general keys. The difference between general key and card key is that above 30m long distance RF communication for lock, unlock door access command is not applied in card key, but general key have that function. But later these long distance RF functions will be replaced by cellular phone and only adjacent distance RF function will remain as emergency key function. As already people are becoming accustomed to these convenient systems, they are really keen to use portable card key that can be carried in the wallet, small size and therefore much more convenient than general big size key.

Card keys in the markets have big thickness due to the electric components, circuit boards, battery and emergency key blade geometry. So, important thing to make card key more usable is to reduce the thickness of each electric components and to make appropriate configuration together with production method. Configuration applied in the products in the market is to assemble populated PCB (printed circuit boards) between upper and lower housing by inserting lots of

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sub parts. Those kinds of configurations are hard to reduce the thickness to the optimal range from current above 6mm level.

This study shows the proper method to achieve thin thickness cardkey by applying RTM(resin transfer molding) method and constraints we have in using that method such as mechanical composition, printed circuit board, electrical components, molding parameters, components soldering , the way to verify functional durability.

The result shows RTM method is one of the solutions in meeting thin thickness, functional requirement & committing onto the engineering specification.

II. METHODOLOGY STUDY

As keys are the complicated products that do wireless communication with the vehicles, all electrical components populated in the PCB should work at severe environmental usage condition. That means that it should have enough durability, mechanical strength and also have to contain emergency metallic key blade together with the battery in the geometry that can be replaced easily when it is fully discharged. Finding proper methodology to apply in production is the success criteria to make thin thickness possible. Both robust design and commercial aspect should be met in methodology selection.

A. Assembly using injection molding parts

Injection molding using thermoplastic material is widely used in making many shapes of parts that is used in the vehicles and also other industry. Most of the keys are also made by doing assembly of populated PCBs with container housings made from injection molding. To make possible doing assembly of separated housing after doing insertion of electrical parts, it require big thickness almost above 6mm. To have enough strength against external stress, to have water tightness that is essential product requirement, it needs complicated geometry that cause big thickness and cost increase due to multiple production process for assembly. As thermoplastic material has deformation at varied atmospheric high & low temperature change at using environment, it also require many times of tuning process to match exactly between all parts to be assembled.

One of the most used ways to enhance durable strength of product is to fill some epoxy material into the housing, and then do full curing process. But this is not applicable for cardkey because very narrow inside space of the housing does not make possible void-less filling. Even filling time should be long. That's why most of products in the market have big thickness without any filling material inside of the housing even with low strength durability.

B. Insert Injection Molding (thermoplastic resin)

Insert injection molding using thermoplastic resin is the application method to remove any additional assembly process that result in cost benefit. It can make optimal thickness of the required products as all electrical components are encapsulated without having any empty space inside after molding. In automotive industry, this is widely used by inserting hard material or small number of electric components.

As melted, high temperature thermoplastic resin is flowed into the mold at high speed, electrical components should be strong enough to absorb those impact energy and heat transferred during molding process. That's why small number of electrical components that meet this requirement is being used. That's one of the reasons that this can't be applied in cardkey as many sensitive components are being used in key.

Even if the molding is successfully done, the strength that product can have against bending, twisting force is not enough for user's using environment because of unique shape of cardkey. Flat shaped with thin thickness is geometrically very weak in bending and twisting force. As thermoplastic material property does not have strong features, this is not suitable for that.

C. Resin Transfer Molding (Thermosetting resin)

RTM is conventional and most popular encapsulation method in semiconductor industry because of its capability to mold in small and complicated feature. Main purpose of RTM is to protect its circuit and component from physical, chemical & electrical environment. Main material used in RTM technology is EMC (Epoxy Molding compound) and it has very low melt viscosity comparing with general thermoplastic material, so it can flow very narrow gap without damaging component. Most of EMC in the industry is matching its CTE (Coefficient of Thermal Expansion) and shrinkage to other component, so it can minimize product warpage and internal stress to the component. It also has good adhesion to the PCB and other component so it can achieve high reliability performance and it has high electrical insulation performance so it can protect products from ESD.

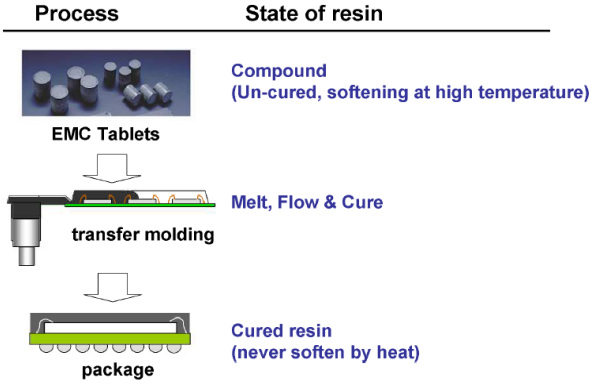


Figure 1. RTM Process

RTM process is performed as Fig.1. After loading products and EMC to the mold cavity, we apply heat and high pressure to let EMC melt down and flow inside cavity at low speed. After complete filling inside cavity, EMC starts to cure. After EMC is cured, it never softens again. After EMC curing is completed, product is unloaded and moved to chamber for final curing. This final curing is called of PMC (Post Mold Curing). With this PMC process, EMC can be fully cured and it can have enough mechanical strength. Electrical performance can be increased and internal stress can be reduced.

Thermosetting resin have good material strength property, so even thin thickness shape of molded card key is expected to have better result. There is no damage onto the component due to low speed flow filling of resin during molding process. Guaranteed water tightness together with ESD protection after molding is a beneficial method that fits well for Cardkey.

III. RTM METHOD APPLICATION

In applying RTM process, below things was considered as main success criteria for card key development.

A. High Temperature & Pressure

The molding atmospheric temperature is around 175℃ at 110~150 bar pressure for 2 seconds, and more than 4 hours post mold curing at 175℃ atmospheric temperature to remove remained stress is required. So insert parts for molding should have characteristic that can withstand those environment.

High melting point & high strength material property for PCB is required not to melt down at high molding temperature and not to deform or deflect due to high pressure imposed by mold flow. CTE value should be also small not to have any deformation. From that reason, widely used FR4 PCB that has low melting point, high deflection rate & high CTE value has to be replaced by kinds of BT PCB that has low CTE value, high melting point & high strength against deflection.

Soldering material that contains lead has low melting point and therefore it is not enough for high temperature molding. Lead-free soldering that has melting point around 230℃ should replace current lead contained soldering process.

Package type electrical components is strong enough to withstand the imposed pressure but in case of crystal made using alloy housing is weak to the pressure, so ceramic housing type crystal should be used not to have any crack or deformed shape of housing that can cause mal-function of frequency generation. Automotive electric components specification usually defines acceptable working & storage temperature, but not defined about the pressure. So this should be verified by doing functioning test after molding.

B. Design restriction of deep hollow geometry

Design change of RTM mold is not free as much as general plastic injection molding method. Once mold is made, change application onto the mold is restricted due to the high temperature molding condition does not allow any metal adding by doing welding onto the mold. That case, additionally welded metals onto the original mold does not have durability in series mass production life time due to imposed high heat. So mold design should be cautiously done.

These kinds of RTM process is widely applied for simple cube shape package without having any inside deep hollow shape or complicated outlook shape. As card key have to contain replaceable deep & thin emergency metal key blade and battery together with a little bit modern outlooks, this is one of the big obstacles considered in designing overall geometry.

As EMC is thermosetting resin and it has quite different material property compared to thermoplastic resin, RTM has much more restricted degree of design freedom in geometry. Due to fine molecular composition of EMC and the property of not changing shape, not melted once molded even in high temperature, deep hollow can cause penetration of resin into the gap between deep core of key blade and base mold. That is hard to repair once happen and can cause product quality and low productivity issue. Even pulling out the deep key blade core after molding can't be done due to high adhesive force of EMC to the key blade metal core. So doing experimental trial for whether pulling out the deep core is possible should be done before fixing design and tool start. Another way to increase possibility of disassembly of deep core after molding is to reduce contact area of deep core and EMC by adding metal sheet to surround the tool core of metal key blade and battery tool core.

C. Internal & external void

Internal or external voids after molding have a negative impact on product performance. Internal void can lessen the strength of product and trapped air inside the void can expand and burst out when environmental temperature is raised. If external void exist, then water tightness is not guaranteed and in electrical static discharge test, it can fail because ESD path is made via that void into the circuit.

To make good mold flow, proper geometry for filling area, correct positioning of gate location and defining correct number of gates, good liquidity of EMC that has good flowing property, correct parameter of molding condition should be harmonized well. Doing mold flow simulation is the key way to predict the result and based on that, mold design should be adjusted. As simulation shows the trend based on many assumed condition that has deviation with real situation, it can be verified only after real tool is made. As many parameters are used in molding condition, to find optimal condition based on the result of DOE (design of experiment) will ease and remove the efforts finding that.

D. Mechanical property and electrical performance

As keys are contained in the wallet or in the pocket, this is exposed to repetitive stress condition due to the force of bending, twisting, compression and sometimes it can have severe impact force due to unintended drop onto the solid surface that can cause breakage. Selecting correct EMC that is suitable for that is a key factor to commit to this requirement and also reinforcement sheet metal adding onto the PCB is helpful for that.

Product should not have big deflection before breakage when external force is imposed to guarantee the electrical components soldered onto the PCB are not damaged. On the other hand, to have a good performance against drop, impact force, it needs to have good property against being fragile. As both two material properties have opposite features with each other, correct EMC material selection can be decided by doing bending & drop test.

As keys can be exposed to ultraviolet radiation for long time or some chemicals, it should have durability against that. As

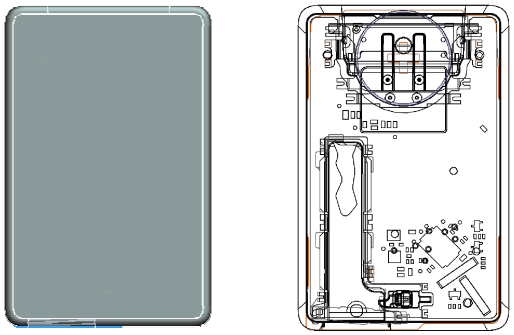
molded parts are used as final outside surface, cosmetic aspect should be considered together.

RF performance is tuned after molding due to the carbon contents in EMC that can cause frequency shift and RF power change and sensitivity for LF receipt. So after molding, detail tuning for this LF/RF matching is required.

It needs special test software to make the best resonance frequency and RF power with antenna matching circuit which gives an effect to battery life time of the card key as well. The best RF antenna matching can save a current consumption of battery and can guarantee more than 2 years of lifetime. That is one of extremely important items for the card key as small size of battery should be applied.

IV. RESULT

Optimal geometry was made as Fig.2 based on the results of FEA(Finite Element Analysis), mold flow simulation mainly. A main geometry features this design has are that 3.4 mm overall thickness, containing exchangeable 1.2 mm thickness battery and 1.5mm thickness metal emergency key blade. All electrical functions required for passive door access, engine start & stop and TP communication for emergency is included.



(a) (b)

Figure 2. a) Card key outlook, b) Inside geometry

A. *Electrical requirement*

As populated PCB does work all electrical performance, verification of whether electrical performance is affected after molding is important. Result shows some frequency shift impact exists after molding as Fig, 3. Those were within the possible range of some passive component value & SW change.

(a) Before molding (b) after molding

Figure 3. RF frequency resonacne & power

Card keys are easily exposed in very likely ESD affected condition, so it should be robust against worst case Max. 30KV ESD power exposure. In test result, it shows acceptable level but in case any external void exists, 100% failure at Max power happens. So from electrical performance view, elimination of external void is important factor to meet requirement.

Card key should not give any damages to credit cards and cellular phones which can be placed with cardkey with an RF/LF emission noise. Therefore, RF generation and LF reception components should not make any unwanted emission noises with qualified automotive parts. The circuit of the card key has size and height limitation as well. So, it needs an integrated circuit type with a PLL IC/MCU and PCB coil antenna which can be made a thin and small size of the key.

B. *Mechanical requirement*

In bending force test, it showed withstanding more than 300N force without any breakage as shown in Fig. 4. Deflection height at breaking point is around 1 mm thickness. Depending on the EMC kinds, those breaking force and deflection range is different. So kinds of geometrical shape and EMC are the key factors in deciding product strength.

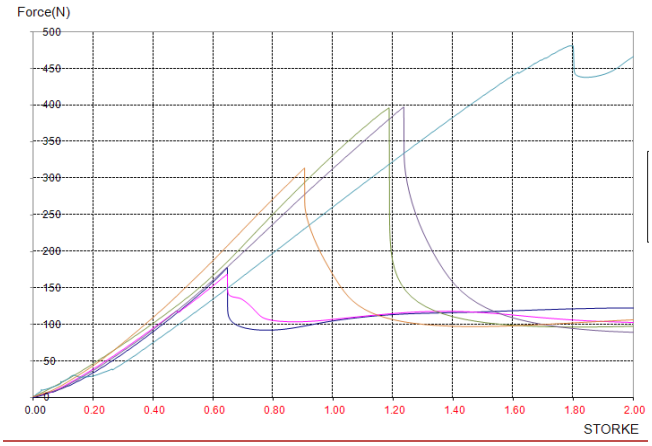
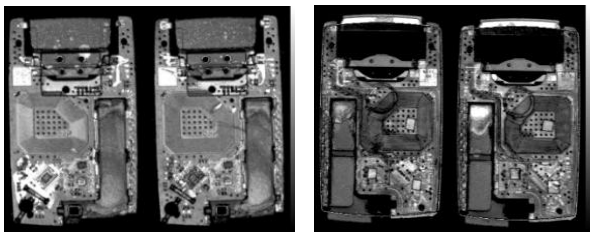


Figure 4. Bending force test: force-stroke diagram

In drop impact test, it does not show any breakage up to 120 times drop at 1.2m height onto the concrete floor. During many times of assembling or disassembling of metal key blade and battery, there was not any damage in opposite molding area. At up to 1000N compression test, it was not broken. In repetitive 1000 times of twisting force at each 4 edges of the product, damage was not found. All electrical function was working after test.

As shown Fig.5, it does not show any de-lamination between EMC and PCB, metal parts, electrical components in ultrasound acoustic test. After 3 weeks storage in high temperature up to 115℃ and in low temperature -45℃, even imposing high pressure with moisture, it does not show any progressive de-lamination. That shows completed adhesion between EMC and other materials.



a) Top view (b) Bottom view

Figure 5. Ultrasonic acoustic test; Top & bottom view

As all electrical components are encapsulated with EMC, it showed water tightness at 2m water reservoir and same result even it is putted in the laundry machine. After exposure to ultraviolet radiation, fading result was within acceptable level for chosen EMC. Anti-scratch and chemical resistance test was within acceptable quality level required in auto industry.

C. Mold parameter fix (reflected DOE result)

Of the many mold parameters, most of the conditions were met for product requirement except for the several times of minor external void happening. For that, DOE was applied in consideration of main factors that have expected much influence on void as Table 1, Fig.6~7. Recommended result from DOE is like below.

TP(Transfer pressure: Ton): 0.56 , TS13(Transfer speed 1-3: mm/s): 4.5, TS45(Transfer speed 4-5: mm/s): 5.0, PHT(Preheat time: S): 5.5, CF(Clamp force: Ton): 47

After applying those parameter, void was eliminated.

TABLE I. DESIGN

	CardKey DOE Molden 2 - Design A2.sta						
Standard Run	1 Trial	2 PreTest	3 TP	4 TS13	5 TS45	6 PHT	7 CF
19	1	no	0,75	1,9	4,0	3	60,0
10	2	no	0,90	3,0	2,0	5	70,0
27 (C)	3	no	0,75	5,0	4,0	3	60,0
14	4	no	0,90	7,0	2,0	5	50,0
9	5	no	0,90	3,0	2,0	1	50,0
26	6	no	0,75	5,0	4,0	3	75,5
20	7	yes	0,75	8,1	4,0	3	60,0
23	8	no	0,75	5,0	4,0	0	60,0
5	9	no	0,60	7,0	2,0	1	50,0
8	10	no	0,60	7,0	6,0	5	50,0
17	11	no	0,52	5,0	4,0	3	60,0
15	12	yes	0,90	7,0	6,0	1	50,0
11	13	no	0,90	3,0	6,0	1	70,0
25	14	no	0,75	5,0	4,0	3	44,5
18	15	no	0,98	5,0	4,0	3	60,0
2	16	yes	0,60	3,0	2,0	5	50,0
7	17	no	0,60	7,0	6,0	1	70,0
6	18	no	0,60	7,0	2,0	5	70,0
22	19	yes	0,75	5,0	7,1	3	60,0
3	20	no	0,60	3,0	6,0	1	50,0
24	21	no	0,75	5,0	4,0	6	60,0
13	22	no	0,90	7,0	2,0	1	70,0
16	23	yes	0,90	7,0	6,0	5	70,0
1	24	no	0,60	3,0	2,0	1	70,0
12	25	no	0,90	3,0	6,0	5	50,0
21	26	no	0,75	5,0	0,9	3	60,0
4	27	no	0,60	3,0	6,0	5	70,0

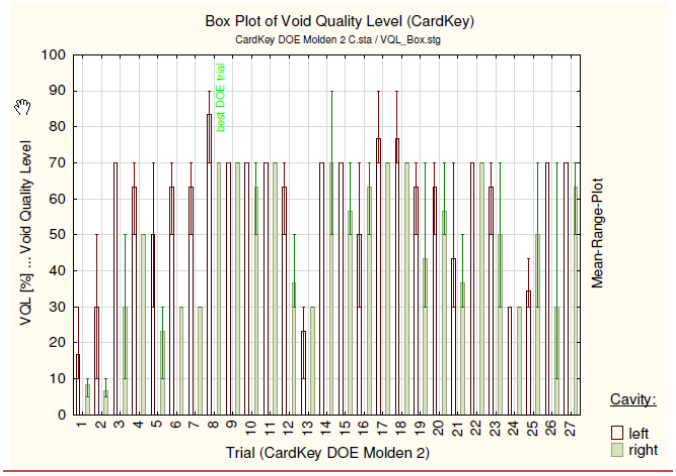


Figure 6. Box plots

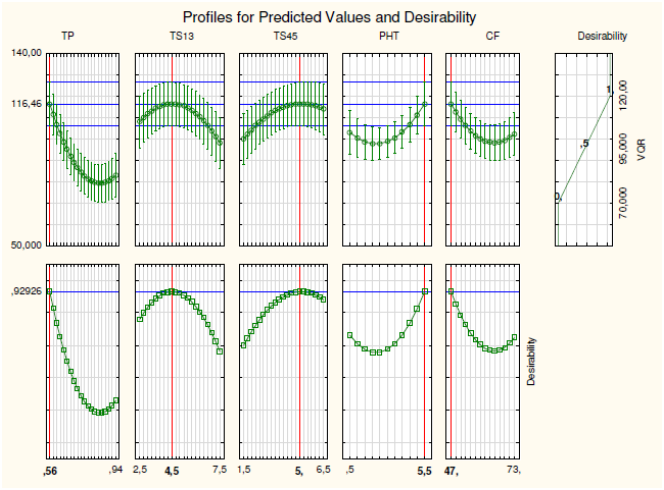


Figure 7. Prdicted value

V. CONCLUSTIONS

In this paper, we could find that applying RTM method is proper approach in making thin thickness card type key used in automotive industry. Things required to overcome in making around 3mm thickness possible within the acceptable quality level was identified with real design. From harmonized condition of electrical, mechanical components to proper production method was the key for the success of the development. Based on this study, diverse kinds of customer demand for thickness and design shape of card key are expected to become more realizable.

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