The Force Measurement of Primary Parts in Frontal Vehicle Crash Test
- by Strain Gauge Calibration -

Park Un-chin **Song Ha-jong*** **Kim Hyun-chul***
Florian Ganz** **Sudar Sankar**** **Mario Wohlfahrt****

ABSTRACT

In this research, the new calibration component test methodology and converted forces from strain gauge will be proposed about measuring real time force of frontal NCAP crash powertrain mounting and structure like front side member.

Key Word : Strain Gauge, Vehicle Crash, Force Calculation, Structure Force Distribution

1. Introduction

Strain gauges are commonly used in Aerospace and vehicle durability tests but not for the vehicle dynamic crash so often. Recently some vehicle crash institutes are applying the strain gauge to predict the vehicle deforming time in case of accelerometer measuring failure or dummy ribs displacement but not for the force measurement. [1)~4)]

To know the force distribution of structure in vehicle crash test is very important because all the strength design of each part can be changed by it. In the CAE, we can easily measure the value it but it's not easy in the real car crash test because the most of structure and inner steel parts like front side member and knee support bracket are in plastic deformation. If we insert the load cell device replacing measuring parts it is possible but this way cannot be used in so many developing tests because those device will influence the test result.

So in this research we will find how to attach strain gauges efficiently to know the component system level real-time force distribution in vehicle crash test with considering avoiding its plastic deformation area. To avoid the trial and error we also developed some component tests which can be tested easily and measured the force. It is very good to find force vs strain voltage synchronizations.

All the measurements are measured again in 14MY Kia YD real vehicle crash test. We could find the synchronization with dynamic component test. Also, we can compare the difference static and dynamic breakage force.

* Safety Performance Team 1 : Author or Co-Author
** Crash Simulation Team : Co-Author
*** ACTS (Advanced Car Technology System) : Co-Author

2. Main Subject

2.1 Powertrain Mounting Breakage Force

2.1.1 Mounting breakage phenomena

Breakage itself cannot be judged as a bad thing because sometimes it helps vehicle crash pulse to stay in low level. But how to control is important if too easily broken there will too much deformation in the passenger compartment. This is the one purpose of this measurement research.

The used YD vehicle is the US model of 1.8 Nu engine auto transmission. Its mountings are 3 points-engine mounting, transmission mounting and roll rod. In case of roll rod the breaking direction and point are too various so we selected measuring position the engine mounting and transmission mounting. Also in the other mounting breakage measuring HKMC has measured its bolt z-direction force so this time we concentrated to these 2 mountings.

In case of YD vehicle crash the chain cover in the engine mounting side is broken. In case of transmission mounting side, there is no broken parts but during the crash the applied force angle is changed from 0 deg to 45 deg.

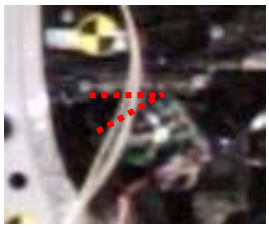


Fig.1 Post picture of YD engine mounting

2.1.2 Component test set-up

To make similar static tensile test of breakage condition with vehicle crash as static condition, we used side door strength test bench. The chain cover of engine is mounted on the jig and the engine mounting is connected to it with engine mounting bracket. We attached 3 strain gauges with x,y and z direction on the bracket considering its load path and flat surface to attach. The other test case is the usage of 3 axis loadcell, replacing the engine mounting bracket.

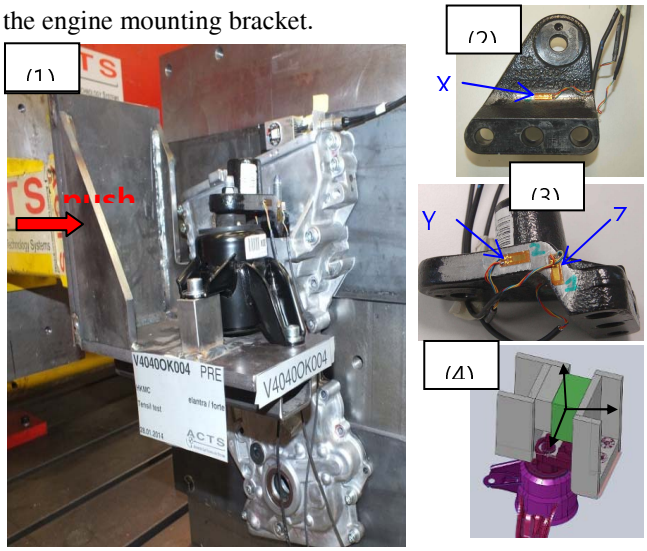


Fig.2 Chain cover breakage tensile test(1)/
Strain gauge position(2),(3)/3 Axis Load cell (4)

In case of transmission mounting breakage component test, we also used jig to mount transmission bracket and the transmission mounting,

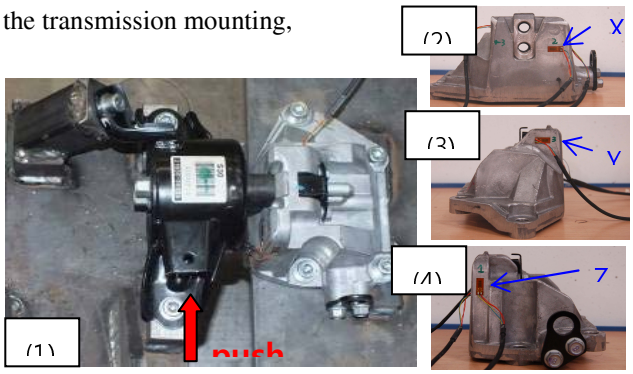
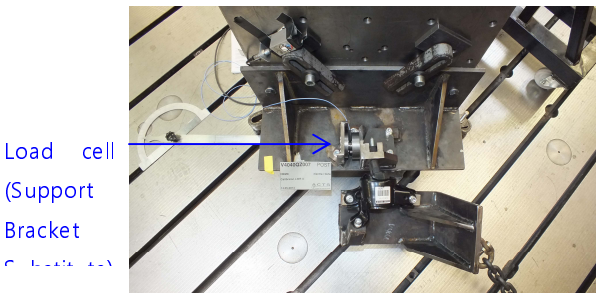


Fig.3 Transmission bracket breakage tensile test(1)/
Strain gauge position(2),(3),(4)

Also, in the crash CAE animation we already know the pushing angle is changed from 0 degree to 45 degree so we made another test chain pulling bench with seatbelt component test device.



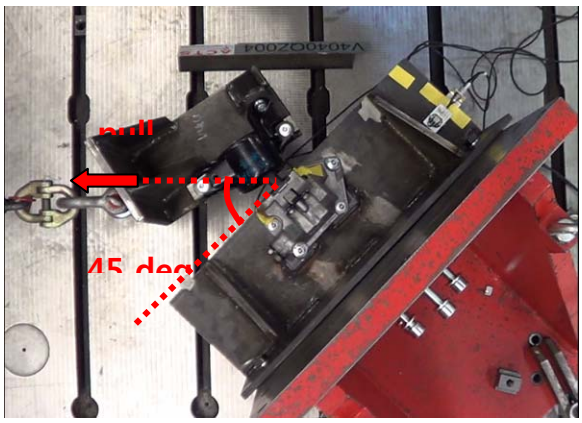


Fig.4 Transmission bracket breakage test with 45 degree
(with loadcell, without loadcell)

2.1.3 Component test result of engine mounting

We pushed the mounting jig in all case except first trial test with 200mm/min. The force limit was 10 ton at pushing test device. The result summary is below.

Tests		Pushing Force (t)	Loadcell (t)	Strain (0.01%)		
			x	x	y	z
ENG	1. Loadcell	**2.1**	**2.1**	-	-	-
	2. Strain gauge	**2.7**	-	2.2	4.5	**2.3**
	3. Loadcell jig	3.0	-	-	-	-

Table 1. Summary of engine mounting breaking force

At the 1st engine mounting test, we used 3 axis load cell to confirm pushing force is equal to the force applied to the engine mounting bracket. Even if there was some breakage failure on the load cell mounting 4 bolts, we can check pushing force and load cell force was exactly same as 2.1 ton.

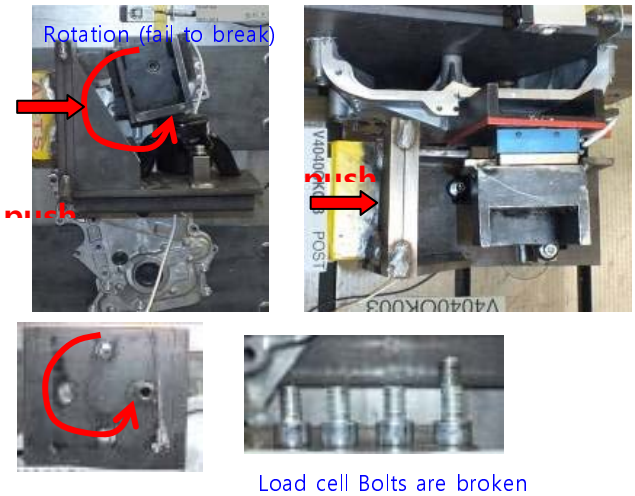


Fig.5 Engine mounting tensile test1 post picture

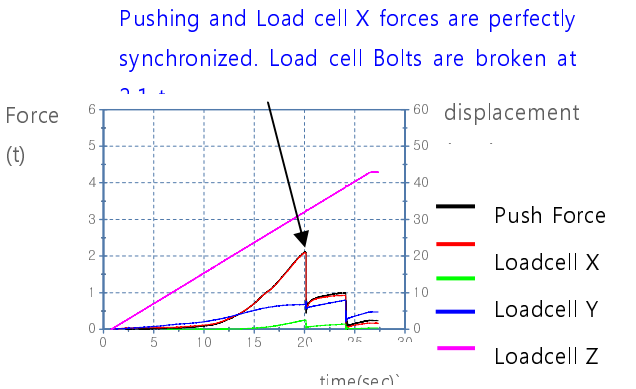


Fig.6 Engine mounting tensile test1 for

At the 2nd strain gauge test, we used the engine mounting bracket as the vehicle with 3 strain gauges attached. As a result, the chain cover rear hole is broken at 20mm displacement with 2.7 ton force. This breaking phenomena was very similar to the broken chain cover in high speed crash vehicle because the broken sequence is from the rear and the section surface is mostly vertical to y and z plane of vehicle.

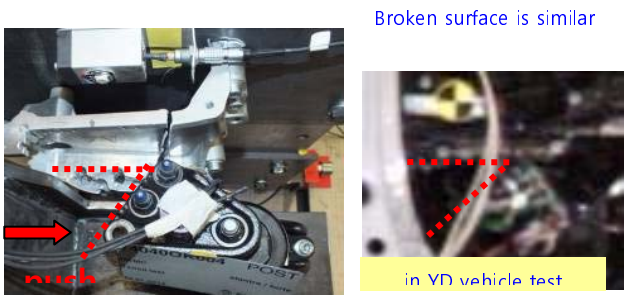


Fig.7 Engine mounting tensile test2 post picture

In this test the all the strain gauges are activated but x and y direction strain gauges activation was too small and the shape is not correspondent. The mode of z direction strain gauge is really synchronized very well to the pushing force. Now we can know this position is good elastic deforming place to measure its load and the load path is very unexpected because its direction is z.

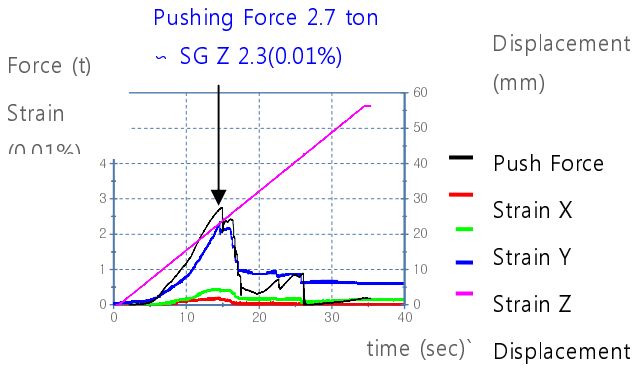


Fig.8 Engine mounting tensile test1 force graph

Also even if we have some rubber material like engine mounting bush on the calibration system we can use strain gauge to find the applied real time force. Now we can use this strain gauge position to fine the force in the vehicle crash test. This would be helpful to adjust the value of breaking force to improve the crash performance.

At the 3rd engine mounting test, we used 3 axis load cell jig again to check the variety of chain cover breaking force. Aluminum die casting breaking force tolerance is well known because it has a lot of air pouch inside when it is created. It has average 175~270Mpa tolerance at 1% strain-stress curve and to the amount of 310 MPa in case of 2% strain.

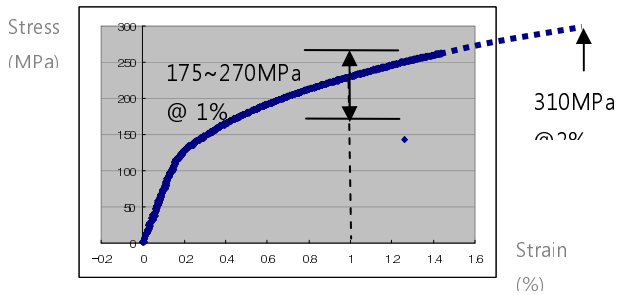


Fig.9 Aluminum die casting strain-stress curve

Because the load cell bolts were broken we attached 3 tucks to resist the breaking moments. As a result of 3rd engine mounting test, chain cover is broken at 3 ton pushing force with similar section surface to the test2. This is just 10% tolerance from 2.7 ton of 2nd test. So this kind of load cell can be used in the vehicle crash test to measure the breaking force instead of the engine mounting bracket only if it is not broken and deformed. The strong point of this load cell application is that it is possible to measure y and z direction force also. Most of engine rotates in y axis so there would be also z direction force.

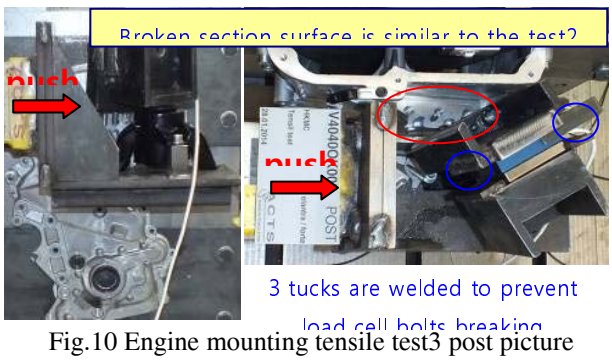


Fig.10 Engine mounting tensile test3 post picture

2.1.4 Component test result of engine mounting

We pushed the mounting jig in all case except first trial test with 200mm/min. The force limit was 10 ton at pushing test device and 7 ton at pulling test device. The

result summary is below

Tests		Pushing Force (t)	Loadcell (t)	Strain (0.01%)		
			x	x	y	z
TM	1. 0 deg) Strain gauge	**5.0**	-	4.3	**5.5**	3.4
	2. 45 deg) Strain gauge	**3.7**	**3.6**			

Table2. Summary of transmission bracket breaking force

At the 1st transmission bracket test, we used the transmission supporting bracket as the vehicle with 3 strain gauges attached. As a result, the bracket is broken at 50mm displacement with 5.0 ton force. This breaking phenomenon did not happen in YD crash test but in case of next model of Elantra happened. So we can use this component test for both cases of transmission supporting broken or not broken to measure the real time force.

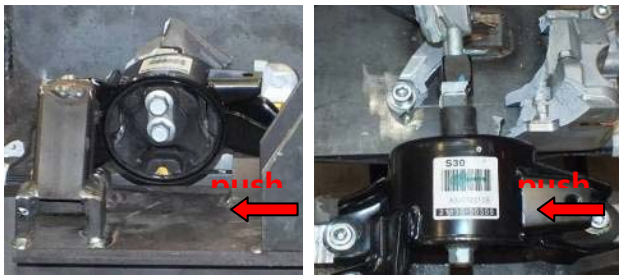


Fig.11 Transmission mounting tensile test1 post picture

In this test the all the strain gauges are activated but x and z direction strain gauges peak was delayed some. we can think this comes from the rubber bush absorbed the force till 23ms because x and z direction strain gauges are attached adjacent to the rubber bush. The mode of y direction strain gauge is really synchronized very well to the pushing force. The only differences are after being broken the smaller fall of strain y and the curve shape in detail. There seem to be come from the elastic system in including rubber but not difficult to see the peak force in transmission bracket.

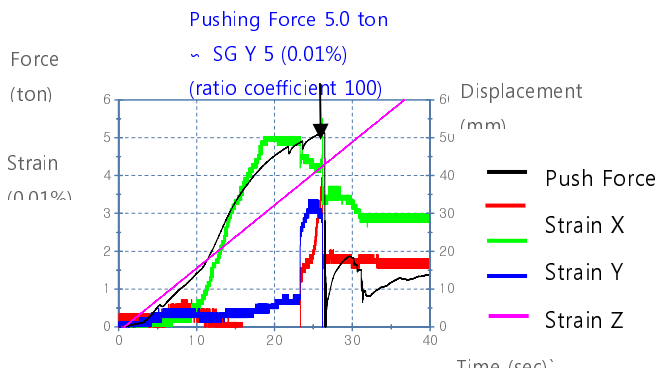


Fig.12 Transmission mounting tensile test1 force graph

Now we can know this position is good elastic deforming place to measure its load. In this case the load path is as expected because its direction is y. Also even if we have some rubber material like transmission mounting bush even there are hard steel bolts inside on the calibration system we can use strain gauge to find the applied real time force. Now we can use this strain gauge position to fine the force in the vehicle crash test. This would be helpful to adjust the value of breaking force to improve the crash performance.

Also we can see at test2 the pushing force is almost same as loadcell value like engine mounting breakage test.

2.2 Front Side Member Crushing Section Force

2.2.1 Calibration Condition

To calibrate the front side member its straightness is very important. In case of YD, the rear lower of front side member has some bending to be connected to the floor side member. So we cut the front side member at the end of its straightness.

To measure YD's front side member we selected 2 x-direction sections which were almost no deformation during the US NCAP crash because if there is some deformation strain gauge value doesn't show the actual applied force. We attached 4 x-direction strain gauges at section1 for each surface one and 10 x-direction strain gauges at section2 for each surface 2~3.

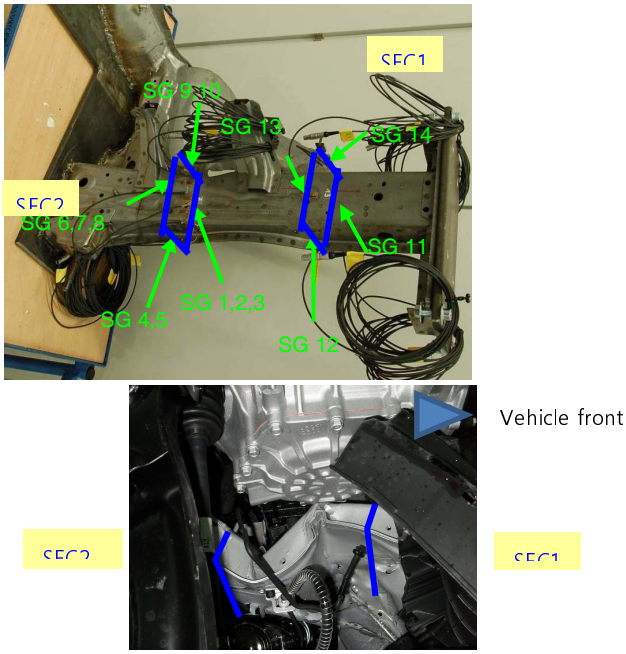


Fig.13 Front side member calibration sections

2.2.2 Calibration Result

We pushed front side member with 3 kinds of force- 2.5ton, 5ton and 10 ton because we already know the fact in RCAR frontal barrier test with load cell inserted to the member section the yielding force of the similar grade

compact car next model of Elantra front side member is 16 ton. As a reference in NCAP test its yielding force s 29 ton.

Force		Strain (mV)			
SG No		11	12	13	14
1st	2.5t	0.05	0.7	0.47	0.26
2nd	5t	0.08	1.36	1.08	0.63
3rd	10t	0.26	2.73	2.13	1.33
Ratio coeffi.		0.98	1.00	1.00	1.00

Table3. SEC1 Summary of front side member calibration

Force		Strain (mV)									
SG No		1	2	3	4	5	6	7	8	9	10
1st	2.5t	0.12	0.07	0.08	0.03	0.95	1.08	0.55	0.56	0.5	0.03
2nd	5t	0.18	0.14	0.15	0.2	1.71	2.07	1.08	0.96	0.94	0.23
3rd	10t	0.51	0.25	0.25	0.1	3.29	4.01	2.12	2.09	2.02	0.43
coeffi.		0.99	1.00	0.99	0.55	1.00	1.00	1.00	1.00	1.00	0.98

Table4. SEC2 Summary of front side member calibration

The correlation was so linear except strain gauge4.

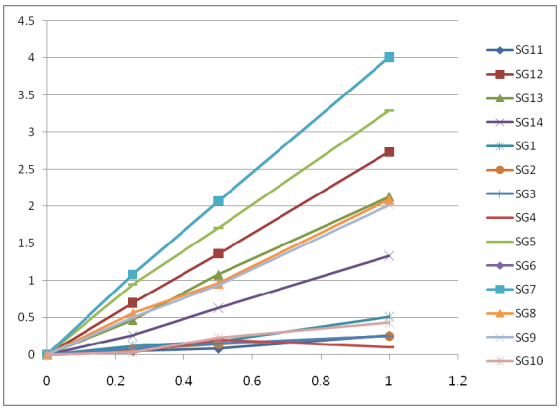


Fig.14 Front side member calibration result

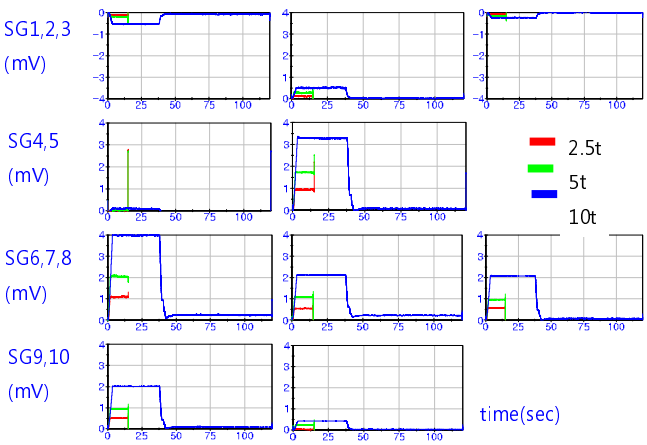


Fig.15. SEC2 calibration result of each strain gauges

The interesting thing is the ratio of each section strain peak average was similar for all 3 forces' test at section2 calibration. But in case of section1 calibration this ratio was not constant because we attached only 1 for each section. This can be useful to find initial yielding direction of the member and can be used to control the vehicle crash dipping value. In case of this YD member we can know the initial principle deformation surface is "inner" and "bottom". When we see Fig12, we can check the member was deformed mostly at inner and secondly at bottom.

Force	outer	bottom	inner	upper
2.5t	1	4	8	2
5t	1	4	9	2
10t	1	3	8	2

Table5. The ratio of each surface strain at SEC2

2.2.3 Member Dynamic Component Test Condition

There are two frontal high speed modes in official crash tests. One is 56kph frontal to wooden flat barrier of US NCAP and KNCAP. The other one is 64kph 40% offset to aluminum honeycomb of EuroNCAP which are used in many country's NCAP. In case of 64kph offset there are some tolerance of honeycomb strength so 56kph frontal mode is better for the research of front side member characteristic.

To realize the YD 56kph frontal in component level, is we used 800kg rear half trolley. At the frontal center of barrier we attached YD's left frontal side member. We attached transmission with its linkage and subframe front mounting link because these have big influences to the member deformation in the real vehicle NCAP crash. as half rigid parts. We also attached 70mm distance the part of YD's crash box because too much hard contact can make some strain gauge noise peak value.

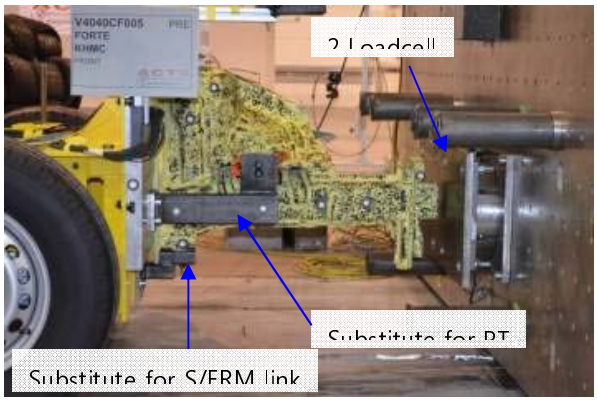


Fig.16. SEC2 calibration result of each strain gauges

It is well known fact when we should lessen the speed in the component level trolley test because the crushing energy is not absorbed by non-existing part. Experimentally we know in case of 56kph frontal, we use 35kph with same test weight for frontal member test. But in this test the trolley total weight was 940kg which is smaller than 1475kg of full car test and only left half hand side member was applied, we used 30.1kph after

calculating same energy. [5)~6)]

$$1/2m_1v_1^2=2*1/2m_2v_2^2 \quad m_1=1390\ v_1=35,$$

$$m_2=940 \quad \text{Then, } v_2=31\text{kph}$$

We also have the other experience, in case of frontal RCAR we use the same speed, 15kph at 70% mass. Even that is not full frontal mode, we know 30.1kph is appropriate number because 940kg is 64% of 1475kg.

At laser displacement measurement, we can know its dynamic peak collapsing was 352mm which is similar to acceleration calculation 372mm. When we compare the trolley x acceleration of the test with YD NHTSA official test x acceleration of rear side sill as a almost rigid part, those mode are similar at the 1st peak value.

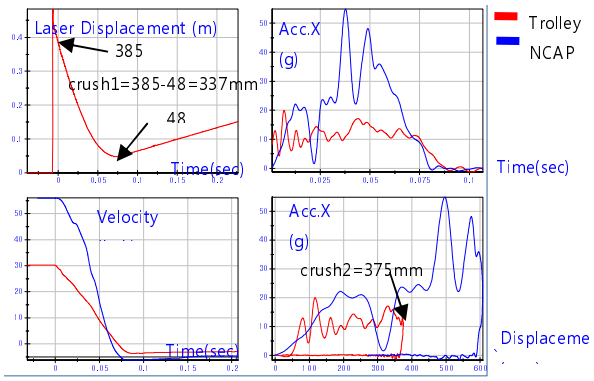


Fig.17. Member dynamic test characteristic

2.2.4 Measured and converted results in dynamic

By each trend line we did get the forces of the primary parts of frontal NCAP like the 2nd row of table.6. Comparing the breakage force of powertrain mountings in the dynamic situation it seems to be needed 2.5~5 times more force to be broken.

Force	Eng MT'g	TM Mt'g	FR MBR SG5	FR MBR SG6
Vehicle	6.9~7.3t	25t		23.1t
MBR Dynamic	-	-	19.7t	21.5t
			15.4t (Loadcell)	
Static Component	2.7t	5t	-	

Table.6 Max Force results

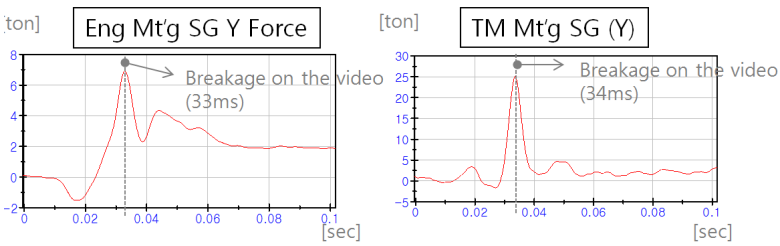


Fig.18. Powertrain breakage force converted from SG

For the member dynamic test, although we attached strain gauges in section1 and crash box there was no effective data but in section2 strain gauge 5 and 6 we got some valuable results when we converted the voltage to the force by previous calibration equations. Especially in strain gauge6, the synchronization is almost perfect. The time based curve shape matching and peak value similarity prove this strain conversion is right. So we can know the section 2 peak force is 21.5 ton. The raw data of barrier load cell has some oscillating we applied CFC60. Because the load was measured in the barrier and the strain conversion to force is for the member section2, the peak values don't have to be same. As we see fig.14 these were the most sensitive strain gauge positions among all the section2 strain gauges.

For the NCAP test measurement, the Force shape is similar to member dynamic test fom 25ms but before 20ms there is no value. We think the force is distributed to other components like hood and fender so there is no value on SG6, even section 2 has some compressing force. As a result we were successful to measure only the 1st highest force 23.1t in the real crash. Even if member dynamic test is not perfect.

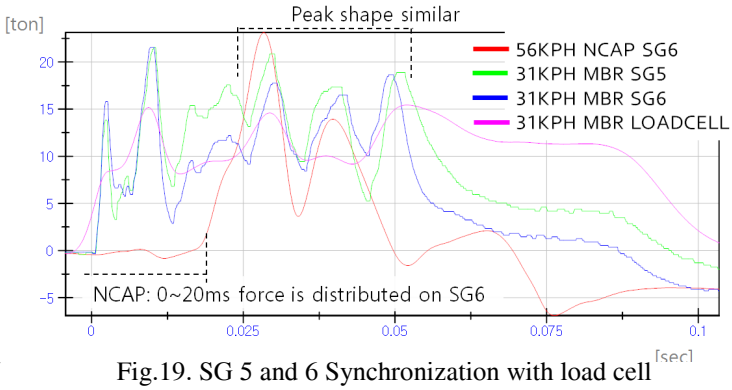


Fig.19. SG 5 and 6 Synchronization with load cell

3. Conclusion

As we discussed at the introduction, knowing the force of each part is very important. If we know, we can optimize the parts' weight and design for the good performance. To this time, those works were in the area of CAE but with this research we can also try more from test data. We expect test numbers frontal NCAP could be reduced half. For one vehicle development the developing cost saving would be over $120,000. We are planning this methodology adaptation from PD project.

We reviewed the component test method of powertrain mountings and front side member with those characteristics. Also wefound how to measure the real time force in powertrain mounting breakage tests and front side member dynamic crush test. The YD's chain cover breakage force in static test was about 3 ton and transmission 5 ton but 7ton and 25ton in dynamic. Front side member max force was 23.1t. These methods can be used in the full car crash tests.

If we stack these measurement and analyze we could

improve the prediction for the crash performance.

■ Patent: Be submitted "Powertrain load cell substitute"

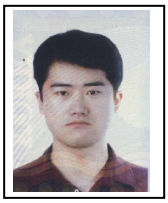
References

1. A. Muniappan, "Computational and Experimental Study on Lift Characteristics of Flapping Wing Micro Air Vehicle" MIT, 2006
2. P. K. C. Wood, " An Improved Test Procedure for Measurement of Dynamic Tensile Mechanical Properties of Automotive Sheet Steels" IARC, University of Warwick, 2007
3. P. K. C. Wood, " Characterising Dynamic Tensile Mechanical Properties of Automotive Materials at High Strain Rate" University of Warwick, 2007
4. Paul Lemmen, "Development of an Advanced Thorax / Shoulder Complex for the THOR Dummy" Paul Lemmen and Bernard Been, 2013
5. Karl Hoffmann, "Eine Einfüfrung in die Technik des Messens mit Dehnungsmeßstreifen", Herausgeber: Hottinger Baldwin Messtechnik GmbH, Sarmtadt
6. Herausgegeben von W.Beitz und K.-H., "DUBBEL TASCHENBUCH FÜR DEN MASCHINENBAU" 20. AUFLAGE

■ Author ■

Park Un-chin

Song Ha-jong


Kim Hyun-chul

Florian Ganz

Sudar Sankar

Mario Wohlfahrt