SIZING AND DESIGN EXPERIENCES OF THE ELECTROSTATIC PRECIPITATORS FOR TWO 600 MW POWER GENERATING UNITS

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ABSTRACT

Hequ Power Plant has two 600MW units burning Hequ coal with its mine very near Zhungeer coal mine. Both coals are low sulfur of 0.44%~0.48%. It is well known that Zhungeer coal is the most difficult coal for ESP applications in China. As a result, ESPs burning Zhungeer coal with large SCA's of 140m^2.s/m^3 and huge actual specific power consumptions of 1740w/1000m^3/h (corresponding a calculating current density of 0.838mA/m2 collecting area) have still operated with dust emissions of 110mg/m3. The selection of a suitable SCA and current density for the Hequ coal ESP was made only after a very careful analysis of the difference between coals. As a result, a much smaller design SCA value of 97.64m^2.s/m^3 and 0.2~0.3mA/m^2 current density were selected; actual operation has proved the design was successful. The number of T/R sets also reduced to one half that used on the Zhungeer coal ESPs.

In addition, the use of a new design method for combining the US top rapped support system with Europe type collecting plates, and the use of special rapping acceleration tests and optimized structural designs resulted in the Hequ ESP achieving a very light specific weight of 26.8kg-steel/per square meter collecting area (2521 ton for one 600MW unit). Comparing this to the average value of Chinese ESPs, about 23% percent less steel was used and more than 1/4 of the cost was saved.

In October of 2004 and February of 2005, these two 600MW ESPs have been put into operation respectively. Satisfactory operation and anticipated emissions were achieved.

INTRODUCTION

Entering year of 2002, China was urgently lacking of electricity. Moreover, long distance transportation of huge amount of power coal gave heavy pressure to Chinese railway. So, at that special time, a lot of new big power plants were built in the vicinity of the big coal mines. One of them was Hequ Power Plant; its first phase contained two 600 MW units. This plant locates at the suburb of Hequ, a county of Shanxi Province, very near the juncture of Shanxi Province, Shaanxi Provinces and Inner Mongolia Autonomous Region. What very interesting is that at this juncture area, there is a "coal triangle", composed of three big coal mines named Zhungeer, Dongsheng and Shenfu, each of them departures from the other two not far than 100km (Figure1). The former two locate in Inner Mongolia and the later in Shaanxi. Although these three big coal reserves are geographically so closed together, but geologically and chemically they are so different to the performance of ESP. In whole China, as we know at present time, Zhungeer coal ash gives the most difficulty precipitation ability and Dongsheng coal ash probably give the best precipitation ability, in spite of that all of them belong to low sulfur coals. Shenfu coal occupies middle level but still belongs in a better one for ESP.

Hequ coal mine locates very near to the coal triangle region, it lies near the middle way of Senfu (about 70km) and Zhungeer(about 40km, See Figure 1). We can naturally consider Hequ coal characteristics are also in the middle level between the both. Because Hequ is an out-of-the-way place, this plant was allowed to have a no more than 100mg/Nm^3 particulates emission instead of 50 mg/Nm^3. By the end of 2002, its ESP project for two 600MW units was undertaking contracted by Shanxi Jinneng Environmental Equipment Company, and the ESP design was sub-contracted by Enelco Environment Technology Company (a subsidiary company of US Evironmental Elements Corporation, briefed as EETC). Under the closely cooperation between Chinese and US engineers, some key technical problems, such as ESP sizing, T/R capacity selection, the design of a Euro-US mixed collection system and the retrofit of a big matrix rapping control system, etc. were successfully solved.

Design work began in February and finished in May of 2003. Unit 1 and Unit2 put into operation in October 2004 and February 2005 respectively. More than one year normal operation gave satisfying emission with lower energy consumptions.

The basic design parameters are listed in Table 1.

ESP SIZING CONSIDERING COAL AND ASH COMPOSITIONS

Table 2 shows the coal / ash characteristics of Hequ coal and coal triangle coals. Four examples of ESP data are also shown in Table 2. The ESP data of Hequ Power Plant are design values; the other three groups of ESP's data are real operation values.

Table 1: Design Parameters and Technical Characteristics of the ESP
For Hequ Power Plant
(For two parallel ESPs of one 600MW unit)

Item	Unit	Data	Item	Unit	Data
Gas flow of one unit	m^3/h	3,457,800	Gas leakage	%	[2.5
Gas temperature	8C	144	Design collection effi.	%	99.85
Flow area	m^2	2×475.5	Number of T/R sets		2×10
Gas velocity	m/s	1.0	Rating output of T/R		
Number of Chambers		2×2	1st field	kV/A	72 / 1.0
Number of Fields		5	Other four fields		72 / 1.4
Channels per chamber		38	Date of operation Unit 1		Oct/2004
Height of coll. plate	m	15.24	Unit 2	M/Y	Feb/2005
Length of coll. plate	m	5×3.945	Type of ESP		
Total collecting. surface area	m^2	91385	Basic ESP		EEC
			Corona electrode		Ridgetrode
SCA	s/m	95.14	Collecting electrode		C480
Spacing	mm	400	Hanging beam of coll. plate		Tadpole
Design gas pressure	kPa	66	Top electro-magnetic rapper		ESI
Gas pressure drop	Pa	[200	Total weight of ESP		2468 t

From Table 2 we can clearly see the relations between ESP performance and coal/ash composition, mainly of sulfur, ash, SiO_2, Al_2O_3, Fe_2O_3, Na_2O and K_2O, perhaps also of water and SO_3 (bold type in Table 2). The more of sulfur, water, Fe_2O_3, Na_2O+ K_2O and SO_3, the less of ash, SiO_2 + Al_2O_3, the better the ESPs worked. It was especially clear of the reversed relation between ESP performance and Al_2O_3.

In China we have suffered the difficulties of Zhungeer coal to ESP performance very much. This coal concentrates almost all the disadvantages factors together, especially the high Al_2O_3 (51.72%) [1]. Zhungeer coal ash kept an average resistivity of 2×10^{13} O-cm in air and an average particle size of only 6.26µm [2]. Its main mineral composition is shown in Table 3 with average data of non-Chinese coals for comparison [3].

Table 2: Coal and Ash Characteristics of the Chinese Coal Triangle and Also of Hequ District

Coal	**Dongsheng**	**Shenfu**	**Zhungeer**	**Hequ**
Coal mine Location	The three corners of Chinese coal triangle			Between Shenfu and Zhunger
Behavior to ESP	Very good	Good	Very bad	Medium
Carbon %	50.84	48.3	55.26	58.8
Sulfur %	**0.82**	**0.51**	**0.43**	**0.48**
Water %	**20.07**	**17**	**10**	**8.4**
Volatile %	35.86	4.35	40.87	37
Ash %	**14.14**	**20.49**	**31.7**	**18.67**
Heat value MJ/kg				22.98
Ash				
SiO_2 %	**23.04**	**44.43**	**38.22**	**48.98**
Al_2O_3 %	**2.24**	**16.21**	**51.72**	**31.32**
$SiO_2+Al_2O_3$ %	25.28	60.64	89.94	80.30
Fe_2O_3 %	**19.46**	**5.27**	**1.38**	**8.29**
CaO %	19.99	26.92	1.36	4.69
Na_2O %	**1.67**		**0.02**	**0.91**
K_2O %	**0.39**		**0.43**	**0.63**
Na_2O+K_2O	2.06		0.45	1.54
SO3 %	**26.12**	**3.9**	**1.75**	**1.53**
ESP	Real operation data			Design value
Power plant name	Dalate	Shenfu	Zungeer	Hequ
Location	Inn.Mongo.	Shaanxi	Inn.Mongo.	Shanxi
Power unit MW	300	~22.3	300	600
Gas flow m^3/h	2,174,000	158,500	2,007,300	3,457,800
ESP Flow area m^2	2x236	49	2x431	2×475.5
SCA $m^2.s/m^3$	~43	49.06	146.4	97.64
Collection Eff. %	99.18	98.1	99.4	99.7
Migr.velo. cm/s	> 10.0	8.2	3.4	5.8

Table 3: Main Mineral Composition of Fly-Ash

Mineral Composition %	Characteristics	Zhungeer Coal Fly Ash	Non-Chinese Coal Fly Ash Average
Quartz	High risistivity, Non-sticky	0.6	19.5
Alunina	High risistivity. Non-sticky	11.7	0.1
Kaoline	High risistivity, Fine particulates, Sticky	45.5	25.9
Alumino Silicate	High risistivity	16.7	2.3
Mixed Al-Silicate	High risistivity	4.0	1.1
Pyrite	Reduce resistivity	0.9	8.3
Iron Oxide	Increase ash diameter	0.4	1.5

From Table 3, we can see again the disadvantages of Zhungeer coal. Although the high resistivity quartz content is very low (0.6%) compared to the non-Chinese coals (19.5%), but SiO_2 appears in the form of high Ai-Si compounds (totally 20.7% vs 3.4%), still play high resistivity roles. High content of high resistivity alumina (11.7% vs 0.1%) gives another difficulty. Moreover, the most striking thing is the very high kaoline clay (45.5%), which contains large amount of high resistivity alumina, gives big possibilities of back corona and conducts bad electrodes rapping because of the fine sticky particulates. Besides, the very low beneficial compositions of pyrite (rich of sulfur) and iron oxide (making large particulates) make Zhungeer coal more difficulty.

In Zhungeer Power Plant, ESP had a very big SCA of 146.4 $m^2.s/m^3$, but still gave a non-acceptable emission of]110mg/m3. The calculated migration velocity is as small as 3.4 cm/sec. In Tuoketuo Power Plant (not far from Zhungeer Power Plant) burn Zhungeer coal also, ESP designed with a small SCA of $87m^2.s/m^3$, gave emissions of as large as $400{\sim}500mg/m^3$. As a remedial measure, SO_3 conditioning device was added in Tuoketuo Plant. It consumes an initial cost of 17 Million Yuan RMB and a year operation cost of 1.8 Million Yuan RMB for two 600MW units.

Contrarily the Dongsheng coal is very beneficial to ESP. With a very small SCA, the ESPs of Dalate Power Plant which burn Dongsheng coal gave very good performance over fifteen years. A migration velocity of more than 10cm/s was gotten. Table 2 shows how good the coal/ash compositions are.

As for Shenfu coal, it basically is a good coal, but not as good as Dongsheng coal. From the operation data of Shenfu Power Plant, a migration of 8.2 cm/s was gotten.

Hequ County lies between Zhungeer and Shenfu district. Hequ coal characteristics also lie between that of Zhungeer coal and Shenfu coal. This can be seen from Table 2. We can judge the migration velocity of ESP for boiler burn Hequ coal should lies between that of Zhungeer coal and Shenfu coal, i.e. lies between 8.2 cm/s and 3.4cm/s. By careful investigation and by the plentiful experiences accumulated in many years, we chosen the design migration velocity as 5.8cm/s, correspondingly the SCA was $97.64m^2s/m^3$. This selection was proved correct by the real ESP operations of two units both. Their emissions were all under the anticipated value.

COMBINED THE US RAPPERS AND THE EUROPIAN COLLECTING ELECTRODES IN ONE ESP DESIGN

The ESP of Hequ Power Plant was designed by Enelco Environment Technology Company (EETC), which used the basic design of her mother company, Environmental Elements Cooperation (EEC). Compact, light and all the moving parts locate outside the ESP shell easing maintenance are its advantage features. But its top positioned electro-magnetic ESI type rappers give small electrodes rapping accelerations compared to the European type ESP with bottom inner rapping. This has been proved by both US and Chinese experiments. Besides, top rapping generally requires all the collecting plates in one row gripped each other to form an integrated panel. This is achieved by the specially designed US type collecting plates with front and rear opposite bending edges. But in Hequ projects, our partner strongly ask us to use their European type collecting plates, the so-called C-480 plates because of they only produce this kind of plates.

Problems were aroused:

- The EEC collecting plate panel has its patented hanging beam, so-called tadpole beam; which is very efficient for gripping and pressing the collecting plate panel from both side surfaces and transmitting the rapping impact. But both of the front and rear edges of C480 plate have a big head with width of 50 mm cannot fit into the lip crevice of tadpole beam.
- The C480 plates are hanged separately on the hanging beam with a chink of about 20 mm between each other. It is different from a whole collecting panel from the point of view of rapping force transmitting. Can top magnetic rappers give enough acceleration to each separated plates?
- The total mass of C480 plates is bigger than the EEC type collecting panel. Can the EEC's standard rapper of 10 feet-pounds maximum (13.56 Joules) produces enough rapping acceleration for dislodging the dust?

By carefully considered these problems and checked its fabricating possibilities, we proposed a special variant (Figure 2), including:

- In view of the tadpole hanging beam have excellent rigidity, momentum transmission capability and metal-saving characteristics; keep its basic form unchanged.
- In order that the C480 plates could be inserted into the two lips of tadpole beam, cut off its front and rear head-edge and press its central ribbed "flat" part to a "real flat" surface at its upper end (about 100 mm). In this procedure, the pressed surface cannot be complete flat and expanded its width a little bit because of the ribbons were pressed flatten.
- To prevent stress concentration, two arc slot were cut out at the front and rear junctions between the head-edge and central flat part.
- Insert the already flattened central part into the two lips of tadpole and firmly bolted with torque-wrench. In this manner, eight C480 plates were fixed on one hanging tadpole beam to form one collecting panel.
- One ESP bus section had 20 rows of such kind of collecting panel. At the top ends of each pair of parallel panel, two small rectangular rapping anvil plates were welded on the tadpole beam ridges at both front and rear ends, so as bearing the knock of rappers
- Increase the lifting height of rapping bars by increase the electrical pulse frequency so to increase the rapping force.

In order to test the effectiveness of the above provisions, an experimental installation was built in manufacturing plant. With two 15 meters high collecting panel composed of eight C480 plates each and two EEC's ESI-type electro-magnetic rappers, the rapping accelerations distributions over the panel surfaces were measured as shown in Figure 3. It shown that all of the acceleration values were bigger than 50g, which is the necessary value for dislodging the dust from the collecting surface in case of top rapping.

Moreover, considering the collecting electrode heights already reach its maximum value up to now----15 m, in order to reduce the transmission loss of rapping force, we moved the rappers from the top of penthouse roof into the penthouse and put them on the top of ESP upper cover plate. This means that the length of rapping bars reduced two meters approximately. The shorter the rapping bar, the easier the knocking force alignment along its transmitting path, thus the better ash dislodging. The highest temperature in the penthouse was not exceeding 50 ~55 ^{o}C in summer; which is in the temperature limits for rapper normal working. One whole summer safe operation was experienced. The only problem was that the spiral coil of the rapper had been some degree inducted by high voltage corona system, giving small discharge from the out shell of the rapper to the earth. This phenomenon was .eliminated after improving the earth ground connection. More than one year operation, Hequ ESP worked well without ash accumulation on the plate surface.

NUMBERS OF T/R SETS REDUCED ONE HALF THAN SO FAR COMMONLY USED IN PREVIOUS DESIGNS

In Chinese coal-fired power plants, for one 600MW unit, it was so far accustomed to provide two parallel ESPs, with each ESP have two chambers and four or five fields. So, there were totally 16 or 20 mechanical bus sections contained in two ESPs for one power unit. Again, each mechanical bus section was divided into two electrical bus sections. Also, it was accustomed to equip one T/R set for one electrical bus section with its output current calculated according to a current density of 40 to 45 mA per square meter collecting plate surface area. This means totally 32 or 40 T/R sets with secondary output parameters of about 1800~2000 mA / 72 kV were equipped for one 600MW unit.

But in long period real operation we found often the actual secondary current readings were very much smaller than the designed rating values. That means, over sized T/R sets were often equipped for Chinese power plants. Another reason for selecting an oversized T/R sets was that when doing air load ESP testament the actual secondary current was much higher than daily working gas load operation. Over sized T/R have drawbacks of waste money, non-stable electrical operation because of un-enough internal reactance and bad control. Especially in case of high resistivity dusts, excessive current can induce back corona.

In view of this, we reconsidered the selection of T/R. Although we have not found a definite relation between the suitable current density value and the characteristics of flue gas and fly ash, but we do accumulated a lot of experienced value at different situations. By careful judgments of the Hequ information, we finally chosen current densities as 0.2 mA/m^2 1st fields collecting plates and 0.3mA/m^2 the successive field's collecting plates respectively. One T/R set served one mechanical bus section, which contains two electrical bus sections. According to this, totally 20 T /R sets were equipped for one 600MW unit, among which four were 1.0 A for 1st field and sixteen were 1.4 A for 2nd, 3rd, 4th and 5th fields respectively. Hence, the number of T/R for Hequ project was only one half of that previous used and the rating output were reduced about 44% to 30%. It means that the total T/R cost was only 40% of the previous value. In air load testing, two T/R sets connected parallel have been done without trouble.

Table 4: Typical ESP Electrical Readings of A 200MW Unit in Hequ Power Plant

ESP	Chamber	Secondary voltage (kV) / Secondary current (mA)				
		1st Field	2nd Field	3rd Field	4th Field	5th Field
No. 1.	A	55 / 256	48 / 401	56 / 994	60 / 1277	59 / 1400
	B	44 / 400	55 / 896	58 / 1293	58 / 1297	60 / 1306
No. 2.	A	40 / 75	43 / 399	54 / 896	57 / 1242	59 / 1398
	B	40 / 42	49 / 398	50 / 798	59 / 1295	56 / 1401
Total energy input =981.43 kW, Specific power input=981.43×1000/3457=283.9 W/1000 m3/h						

Actual operation readings proved the correctness of the T/R selections. The typical operation reading is as Table 4. It is evidently that if we chose 40 T/R sets of 72kV / 1200~1800mA output, great economic waste and worse operation would be occurring.

RAPPERS CONTROL

The number of ESI rappers for one 600MW unit ESP was totally 980, among which 160 rappers were used for corona wires, 800 rappers were for collecting plates and 20 rappers for gas distribution plates. Our former rapping control experience was limited to about 256 rappers for one set of ESP. We have encountered some problems for controlling about one thousand rappers as a whole system in Hequ.

- Because the ESI rapper have very small reactance of only 8 ς and the very long rank connection wires, the wire voltage drop compare to the inner reactance was remarkable. Although because of the distances between the farther and nearer rappers have to apart about 80~150 m, their wire voltage drops differenced very much. This conducted to different rapping bar lift heights, thus different rapping forces. The farthest rapper could only lift its bar less than 100mm, insufficient cleaning the collecting plates. By changing the rank wire to very thick one, i.e. 4 mm^2, giving much small voltage drops, problem was solved.
- In the rapper semi-wave DC energization line, the original freewheeling diode capacity of 10A current and 800V peak inverse voltage was not enough, easily burned down under the high reversed electromotive force caused by the inductance of rappers. As a certain numbers of freewheeling diodes have been burned down, it conducted to one of the two parallel connected thyristors and the solid state relay in the power source circuit burned down also. In this case, as soon as another undestroyed thyristor was triggered, the 380 V power source circuit was shorted without good protection, caused the whole rapping system paralyzed. In order to overcome this drawback, firstly bigger freewheeling diode of 20A / 1200V freewheeling diode was used instead of the former small one. Next improve power source circuit and the protection devices, including use isolating transformer or changing to bridge rectifier with solid state relay and current transformer..
- The original control philosophy was incorrect. The total 980 rappers, neither make no distinction between corona, collecting or gas distributing systems, nor make distinction between first to fifth fields, they were mixed together giving unsatisfying rapping time periods. Again, imperfect software design gave unfriendly interface. In order to adjust the rapping periods of so many rappers on-site, about 20 hours troublesome works had to be done. So, a new control program; which giving different rapping periods and intensity between electrode polarities and inlet to outlet fields, were adopted. Moreover, this new program, considering less than 2 hour as one time adjusting unit, was convenient for rapping period and intensity adjustments.

In spite of principally the rapping control is not complicate, several months on-site testing were spent and another almost entirely new designs had been done.

METAL AND ENERGY CONSUMPTION

Because of all the moving elements located on the roof outside the ESP shell, side access platform was unnecessary. As well as the compact and scientific structural design made the total weight of one 600MW unit ESP only 2521 tons. Specific metal consumption had been only 26.8 kg/m2 collection surface area, about 7~15% less than the Chinese common level.

Normal operation electricity input as Table 4 lists was 981.43 kW, corresponding to unit gas flow spending of 283.8 W/1000m^3/h at 99.85% efficiency. This value is just equal to the level for 99.87% efficiency according to the statistics of US EPRI[4]. But it is much less than that of a lot of Chinese fly ash ESP had. For example, the ESP of Zhungeer Power Plant consumed electricity of 1740w/1000m^3/h at about 99.6% efficiency.

CONCLUSION

- There is a famous coal triangle in China characterized by its huge reserves and very different influences to the performance of ESP. Both Hequ coal mine and Hequ coal ash's precipitation ability lie between that of Zhunger and Shenfu , the two point tips of this triangle.
- Relatively accurate ESP sizing based on the Chinese coal knowledge accumulated in recently years gave a good base of Hequ ESP satisfying operation and emission.
- Relatively accurate selection of T/R number and capacity gave almost 50% electrical saving than some other designs in China.
- The first trial to combine the European and US collecting systems design is successful.
- Experienced many failures, a large matrix top rapping controller was developed.
- While maintaining high collection efficiency, about seven to fifteen percentage metals were saved.

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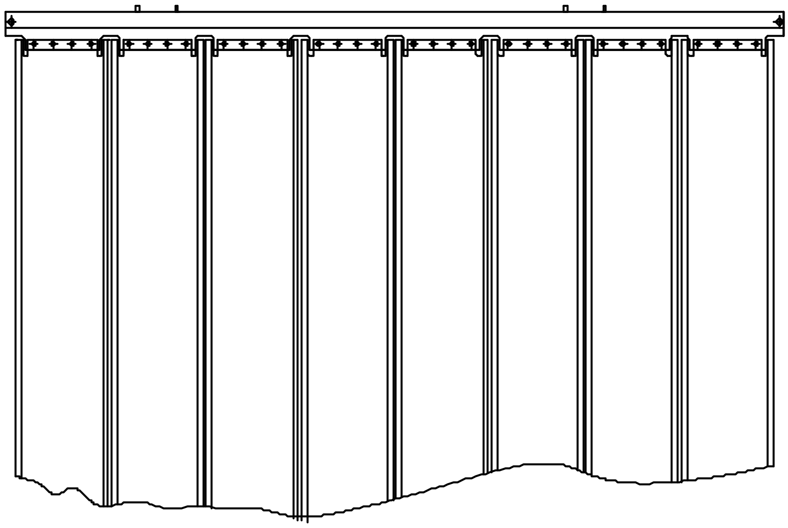
Figure 1: China coal triangle



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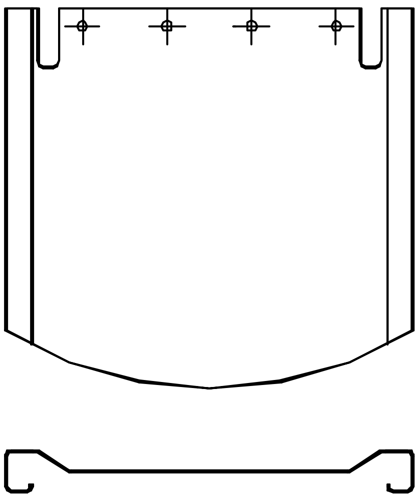
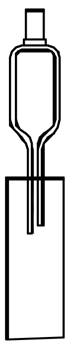
Collecting electrode panel (8 Modules collecting plates)



C480 type collecting plate



Top Tadpole & C480 Plate Connection

Figure 2 The combination of EEC's tadpole beam and European collecting plates

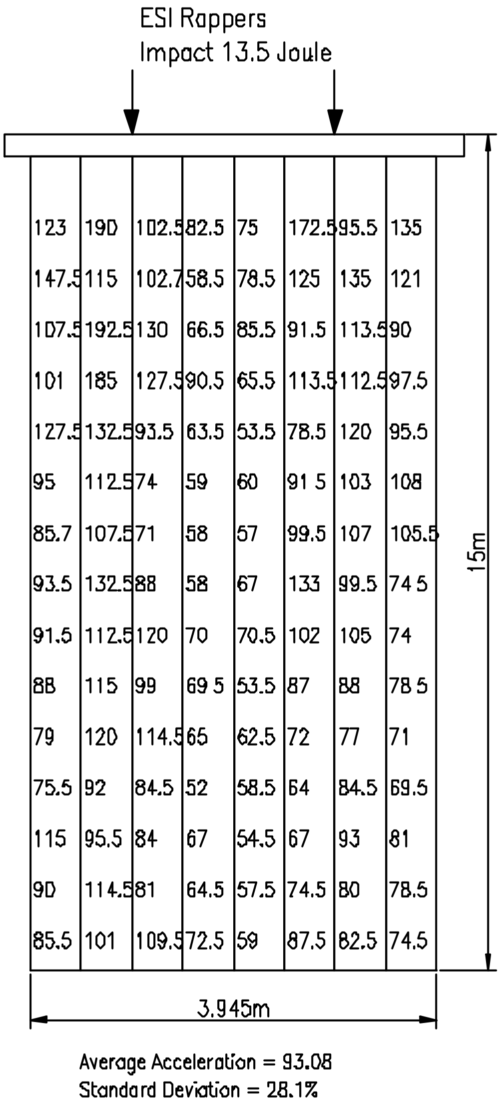
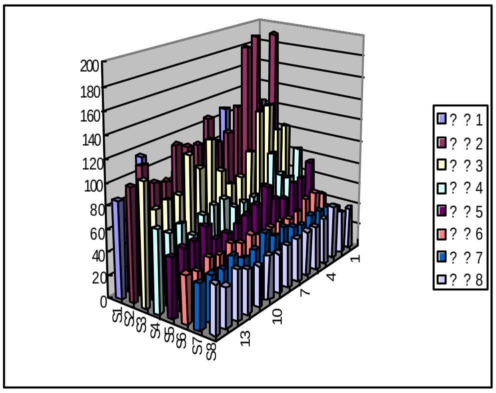
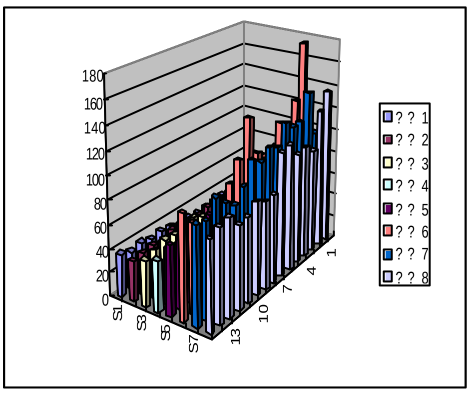


Figure 3: The measured rapping acceleration values



Left side rapping acceleration diagram



Right side rapping acceleration diagram