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Test Report

CANFLEX Fuel Bundle Strength Tests

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Korea Atomic Energy Research Institute

제 출 문

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본 보고서를 "중수로용 개량핵연료 검증시험" 과제의 "CANFLEX Fuel Bundle Strength Tests (Test Report)" 기술 보고서로 제출합니다.

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KAERI/TR-CX201
CANFLEX-105
Revision 0

Test Report

CANFLEX Fuel Bundle Strength Tests

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1997 April

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1. INTRODUCTION

This report describes the strength test results of the CANFLEX fuel bundle which were completed in March 1995. The strength tests were planned to simulate the normal fuel loading by the double side-stop test, and abnormal fuel loading by the single side-stop test. In both tests the load was applied by controlling the flow to obtain a desired pressure drop across the whole fuel string resulting in a hydraulic drag force on the whole fuel string which produced the load on the test bundle.

2. TEST OBJECTIVE AND ACCEPTANCE CRITERIA

CANFLEX fuel bundles are subjected to various short and long term axial loads throughout their normal life. In almost all cases the axial load is shared by all the 43 elements but only the outer 35 elements are involved when the bundle is loaded against the shield plug. In all the above cases the load on the element is a central axial load.

The fuel is also supported temporarily by double side-stops in the fuelling machine in order to separate the bundles in the channel from those in the machine. This type of loading is more severe because:

- Only about 8 elements share the load
- The load is applied eccentrically on the element end-cap causing temporary bow of the element.

If there is a fuelling machine malfunction and one side-stop cannot be driven in, the fuel may be supported on only one side by a single side-stop. This is an abnormal procedure after which fuel loaded against the side-stops would be discharged. When the fuel is resting against side-stops the loading is caused by hydraulic drag forces only.

The main objectives of the strength tests of CANFLEX fuel bundles are to determine whether the fuel will withstand the normal and abnormal loads imposed during refuelling and whether the fuel can be discharged from the reactor without difficulty after experiencing abnormal refuelling loads. The amount of outer element bowing and general bundle shape distortion of CANFLEX fuel bundle will be determined for each case, to define typical operating margins.

The acceptance criteria at completion of the test as specified in the Test Specification of CANFLEX bundle strength tests [1] are as follows.

- There is no significant distortion;

- There is no significant fuel element length change and/or end plate profile change due to fuel element bowing;

- The tested bundles pass though the kinked tube gauge; and

- There is no significant bearing pad wear, or marking of the fuel element endcaps.

3. DESCRIPTION OF TEST APPARATUS AND TEST BUNDLES

3.1 Test Bundles

The CANFLEX fuel test bundles were fabricated in the KAERI fuel fabrication plant in accordance with Technical Specifications of CANFLEX-NU bundle [2]. The test fuel bundle string consists of 3 test bundles and 12 filler bundles.

3.2 Test Rig

The bundle strength test set-up as shown in Figure 1 consists of a pressure tube with the inlet and outlet end fitting. The side-stop simulator was designed and fabricated carefully to fit correctly into outlet end fitting (see Figure 2). Two special inserts were fabricated, to simulate a double and a single side-stop assembly. These were placed in the fuel channel to allow the coolant flow to provide the axial forces required for the tests. The bundle strength tests were performed in the CANDU Hot Test Loop facility [3] which can simulate reactor operating conditions during the refuelling process.

3.3 Data Measurement Apparatus

Pressure taps were connected along the length of test rig, as it is shown in Figure 1, to measure pressure drop across the pressure tube. All the system parameters (pressure, temperature and flow rate) were measured from the Hot Test Loop data acquisition system (HP3054A, Hewlett Packard); See Table 1.

4. DESCRIPTION OF TEST PROCEDURE AND QUALITY ASSURANCE

4.1 Test Conditions

Two strength tests were performed; one double side-stop test and one single side-stop test. For each of the tests, the specified coolant temperature and the inlet pressure were set to 120 ℃ and 11.2 MPa, respectively [1,4]. These conditions were held for 15 minutes. In each test the coolant flow was adjusted to establish a specified fuel string ΔP resulting in hydraulic drag force against side-stop. The specified fuel string ΔPs correspond to the maximum (13.1 bundles) number of fuel bundles which reside in the axial flow region of the fuel channel. The specified fuel string ΔPs were derived from the following equation as it was reported in the strength test procedure [4].

$$\Delta P = \frac{Specified\ Drag\ Force}{Pressure\ Tube\ Cross-Section\ Area^{*}}$$

1) Double Side-stop test

$$\Delta P = \frac{12010(N)}{8.487\times10^{-3}(m^2)} = 1420(kPa)$$

2) Single Side-stop test

$$\Delta P = \frac{7300(N)}{8.487\times10^{-3}(m^2)} = 860(kPa)$$

* The cross sectional area of the pressure tube has been always used for calculation of drag force across string of bundles (see Appendix A, Reference 1).

4.2 Bundle Alignment

The fuel bundles were loaded into the channel with marked ends facing upstream. The positions and orientations are shown in Figure 3. For alignment, the reference line (12 o'clock position) was scribed 67.5° clockwise referenced to the centerline of the element 18 on the marked end of the test bundles in position 15. Bundles KF9414 and KF9426 were used for double side stop test, and single side stop test repectively. On the marked end of bundle in positions 14 (bundle KF9427) and 13 (bundle KF9428), the reference lines were scribed the same angle as bundle #15. The other 12 bundles(#12 to #1) were randomly oriented. In the double side stop test, the elements that pushed against the double side-stop were 3, 4, 6, 7 and 16, 17, 19, 20 as shown in Figure 4. After the double side-stop test, the whole fuel

string was removed from the fuel channel and the double side-stop simulator was replaced with the single side-stop simulator for the single side-stop test. Then, the test bundle KF9414 (used for the double side-stop test) was replaced with test bundle KF9426. The elements resisting against the single side-stop were 16, 17, 19, 20. The remaining fuel bundles were loaded again into the fuel channel in the same orientations and order as for the double side-stop test.

4.3 Test Procedure

The strength tests were performed in the following order[4].

1) Both blind flanges of the fuel channel and shield plugs were removed.
2) The side-stop assembly was aligned so that the center line between the two side-stops was located at the 12 o'clock position.
3) The outlet end fitting was installed and the pressure tap was connected using Swagelok fittings.
4) The test and filler bundles were loaded as specified in section 4.2.
5) The inlet end fitting was assembled.
6) The test rig was filled with water, vented, pressurized and warmed up to the test conditions and the folw rate through the test section was controlled less than 5 kg/s.
7) When the loop was stabilized at the test conditions, the flow was adjusted to get the desired pressure.
8) The test was run for 15 minutes recording the ΔP for feeder to feeder and flange to flange, flow rate, loop pressure and temperature every 2 minutes during the test.
9) After the test, the rig was depressurized, and cooled. The test bundle KF9414 and double side-stop assembly were replaced with the test bundle KF9426 and single side-stop assembly.
10) Items 3) to 8) were repeated to perform the single side-stop test.
11) After the test, the rig was depressurized, cooled and the test bundle was removed for the bundle characterization.

4.4 Measurements of Fuel Bundles

The following measurements were made on each of the test bundles loaded against the side-stop simulator before and after testing:

- Element lengths over the end plates;
- End plate profiles of the plain logo end of the bundle, with the bundle placed in a horizontal position in a half piece of pressure tube;
- Sheath axial profiles near the element ends for all outer elemnts at both the plain and logo ends of the bundles;
- Bundle average diameter over bearing pads at all three planes (Π-tape measurement);
- The test bundles passed through the kinked tube gauge;
- Outer element bow; The element bow measurement positions are shown in Figure 5.
- Minimum clearance between outer elements for all pairs of outer elements;

4.5 Quality Assurance

The rig was set and operated according to the Hot Loop Test Operating Manual [3]. In addition, the procedures were prepared and the tests were performed in accordance with Appendix B of the Test Specification for this test [1].

Data Record

The "Test Plan" including test witnessing records are stored in "Fuel Thermal-hydraulics Department" at KAERI. The computer files related to the data acquisition and the loop control are stored in the computers in the laboratory. The test log book is also stored in "Fuel Thermal-hydraulics Department". Calibration records of the rig instrumentation including those used for bundle dimensional measurements are filed in documents at "Fuel Thermal-hydraulics Department".

5. RESULTS AND DISCUSSION

5.1 Double Side-stop Test

1) Loading Conditions

Bundle KF9414 was subjected to double side-stop test under the test conditions shown in Table 2. The minimum pressure drop across the fuel string was 1402.279 kPa at a flow rate of 39.31 kg/s. The force acting on the test bundle was calculated as follows.

$$\begin{aligned} \text{Hydraulic Force} &= \text{Bundle String } \Delta P \times \text{Pressure Tube Area} \\ &= (1402.279\ \text{kPa}) \times (8.478\text{E-}3\ \text{m}^2) \\ &= 11888\ \text{N} \end{aligned}$$

The maximum predicted force exerted by the fuel on the side-stops is 7300N [1] in reactor. The test force of 11888N established a minimum operating margin of 11888/7300 = 1.63 that exceeds the required factor of 1.6 (see Appendix A, Reference 1).

2) Element Length

The element lengths before and after the test, and their changes are shown in Table 3. Before the test, the reference bundle length was 495.38 mm and the maximum deviation of the elements was 0.295 mm which is within the requirements of 0.56 mm specified for the CANFLEX bundle [5]. After the test, the reference bundle length was 495.36 mm. The maximum length was 0.003 mm shorter on element 1 and the minimum length was 0.247 mm shorter on element 5 compared with the reference length. Therefore the maximum deviation of the elements was 0.244 mm which is also within the requirements [5]. After the test, about 86 % of the elements (37 elements) were decreased in length. The maximum change in element length was 0.103 mm decrease on element 7. The measurement results are quite reasonable and the length changes are within the requirements.

3) End Plate Profile

The end plate profile measurements for the marked and plain ends of the test bundle are shown in Table 4 and 5. Before the test, the maximum local waviness was 0.203 mm on the marked end and 0.232 mm on the plain end. After the test, the maximum local waviness was 0.355 mm on the marked end and 0.442 mm on the plain end which is within the requirements of 0.56 mm [5]. After the test the maximum waviness was 0.659 mm on the marked end and 0.776 mm on the plain end which is within the perpendicularity requirements

of 1.80 mm [5]. The maximum changes in profile before and after the test were 0.394 mm between element 26 and 27 on the marked end and 0.383 mm on element 27 on the plain end. Part of the end plate which was against the side stop was pushed into the bundle on the plain end and pushed out of the bundle on the marked end. Also part of the intermediate ring and web close to the side-stops were deformed in the same configuration as the end plate. The end plate profile changes are not large and are within the requirements.

4) Sheath Distortion

The sheath distortion measurements for the marked and plain ends of test bundle are shown in Table 6 and 7. The maximum sheath distortions on the marked end were detected on element 1 (concave) and 3 (convex) respectively before and after the test. Element 1 was distorted 0.088 mm before the test and 0.106 mm after the test referenced to the marked end plate while the element 3 was distorted 0.061 mm before the test and 0.071 mm after the test. The maximum distortion change was 0.126 mm on element 17 with reference to the marked end. The maximum sheath distortions on plain end were 0.074 mm concave on element 1 and 0.060 mm convex on element 6 referenced to the plain side end plate. After the test, the maximum sheath distortions referenced to plain end were 0.198 mm concave on element 7 and 0.056 mm convex on element 5. The maximum distortion change was 0.237 mm on element 7 on the plain end. No remarkable sheath distortions occurred during the test.

5) Element Bow Measurements

The element bow measurements for the X and Y positions of each outer elements are shown in Table 8 and 9. Before the test, the maximum bow in X-position was 0.33 mm concave on rod 1 and 0.13 mm convex on rod 5. These occurred at positions "B-H" (see Figure 5). After the test, the maximum bow in X-position was 0.49 mm convex on rod 17. This occurred at the middle of elements at positions "F" and "H" (see Figure 5). The masurements show that the bending of the elements occurred with concave shape at the middle position. The maximum bow in Y-position for each element was measured at rod ends with similar values (0.30-0.43 mm) before the test. These measurements showed that the bundle was slightly twisted to one direction. After the test, the maximum bow in Y-position was 0.43 mm on rod 5. It was noticed that element bow at rod ends were reduced after the test. This shows that twisted bundle before the test was returned to straight shape after the test.

6) Minimum Clearance Measurements

The minimum clearance measurements of outer elements on the marked end are shown in Table 10. The minimum clearances between outer elements were 1.55 mm before the test and 1.57 mm after the test between rods 5 and 6. The maximum clearances were

1.69 and 1.72 mm before and after the test respectively, between rods 4 and 5. The maximum clearance change was 0.05 mm reduction between rods 21 and 1. All the clearances met the minimum clearance requirements [5].

7) Π Tape Measurements and Kinked Tube Gauge Test

The Π tape measurements and kinked tube gauge test results are shown in Table 11. Although the bundle length was slightly decreased and element bowing was increased after the test, the Π tape measurement results were satisfactory and the bundle passed through the kinked tube gauge under its own weight.

5.2 Single Side-stop Test

1) Loading Conditions

Bundle KF9426 was subjected to single side-stop test under the test conditions shown in Table 12. The minimum pressure drop across the fuel string was 862.281 kPa at a flow rate of 32.47 kg/s. The force acting on the test bundle was calculated as follows.

$$\begin{aligned} \text{Hydraulic Force} &= \text{Bundle String } \Delta P \times \text{Pressure Tube Area} \\ &= (862.281\ \text{kPa}) \times (8.478\text{E-}3\ \text{m}^2) \\ &= 7310\ \text{N} \end{aligned}$$

The test force of 7310 N exceeds the force requirement of 7300 N specified in Reference 1.

2) Element Length

The element lengths before and after the test, and their changes are shown in Table 13. Before the test, the reference bundle length was 495.46 mm and the maximum deviation of the elements was 0.449 mm which is within the requirements of 0.56 mm specified for the CANFLEX bundle [5]. After the test, the reference bundle length was 495.36 mm. The maximum length was 0.215 mm longer on element 8 and the minimum length was 0.273 mm shorter on element 29 compared with the reference length. Therefore the maximum deviation of the elements was 0.488 mm which is also within the requirements [5]. After the test, 98% of the elements (42 elements) were decreased in length. The maximum change in element length was 0.181 mm decrease on element 16. The measurement results are quite reasonable and the length changes are within the requirements.

3) End Plate Profile

The end plate profile measurements for the marked and plain ends of the test bundle are shown in Table 14 and 15. Before the test, the maximum local waviness was 0.282 mm on the marked end and 0.215 mm on the plain end. After the test, the maximum local waviness was 0.278 mm on the marked end and 0.279 mm on the plain end which is within the requirements of 0.56 mm [5]. After the test the maximum waviness was 0.525 mm on the marked end and 0.571 mm on the plain end which is within the perpendicularity requirements of 1.80 mm [5]. The maximum changes in profile before and after the test were 0.295 mm on element 17 on the marked end and 0.380 mm between element 16 and 17 on the plain end. Part of the end plate which was against the side stop was pushed into the bundle on the plain end and pushed out of the bundle on the marked end. Also part of the intermediate ring and web close to the side-stop were deformed in the same configuration as the end plate. The end plate profile changes are not large and are within the requirements.

4) Sheath Distortion

The sheath distribution measurements for the marked and plain ends of test bundle are shown in Table 16 and 17. Before the test, the maximum sheath distortions on the marked end were 0.109 mm concave on element 7 and 0.094 mm convex on element 5. The maximum distortion change was 0.506 mm on element 1 on the marked end. The maximum sheath distortions before the test on the plain end were 0.086 mm concave on element 1 and 0.062 mm convex on element 14 referenced to the plain end plate. After the test, the maximum sheath distortions on the plain end were 0.99 mm concave on element 17 and 0.17 mm convex on element 6. The maximum distortion change was 0.918 mm on element 17 on the plain end. No remarkable sheath distortions were occurred during the test.

5) Element Bow Measurements

The element bow measurements for the X and Y positions of each outer elements are shown in Table 18 and 19. Before the test, the maximum bows in X-position were 0.32 mm concave on rod 7 and 0.20 mm convex on rod 6. After the test, the maximum bows in X-position were 0.17 mm convex on rod 5 and 0.36 mm concave on rod 7. The maximum bow occurred at different positions before and after the test. The maximum bow in Y-position for each element was at rod ends with similar value (0.36-0.52 mm) before the test which means that the bundle was slightly twisted to one direction. After the test, the maximum bow in Y-position was 0.48 mm on rod 2. It was noticed that element bow at rod ends were reduced after the test. This shows that twisted bundle before the test was returned to somewhat straight shape after the test.

6) Minimum Clearance Measurements

The minimum clearance measurements of outer elements on the marked end are shown in Table 20. The minimum clearance between outer elements was 1.58 mm before the test between rods 20 and 21. The maximum clearance was 1.64 mm between rod 19 and 20 before the test, and was measured the same between rod 7 and 8 after the test. The maximum clearance change was 0.02 mm increase between rod 18 and 19. All the clearances met the minimum clearance requirements [5].

7) Π Tape Measurements and Kinked Tube Gauge Test

The Π tape measurements and kinked tube gauge test results are shown in Table 21. Although the bundle lengths were slightly changed compared with the pre-test condition, the Π tape measurement results were satisfactory, and the bundle passed through the kinked tube gauge under its own weight.

5.3 Discussion of the Measurements and Results

The summary of the bundle measurements and results is shown in Table 22. In the case of double side-stop strength test, the bundle element lengths were decreased for approximately 75 % of the elements. Part of the end plate close to the side stop was pushed into the bundle on the plain end and pushed out of the bundle on the marked end. The element bows in X-position occurred at the mid-plain. In single side-stop test, about half of the elements were decreased and others were increased in length. In this test, the dishing-in and out of the bundle was also observed on both end plates. After the strength tests, both double and single side-stop test bundles passed through the kinked tube gauge under their own weights. All the measurements for both strength tests met the acceptance criteria.

6. CONCLUSIONS

The double and single side-stop strength tests for the CANFLEX fuel bundle were performed successfully. The test flow rates for applying required hydraulic force on the test bundle were maintained during the tests.

The inspections and measurements of the test bundles showed that the CANFLEX fuel bundles satisfied the strength test acceptance criteria as follows:

1) Both test bundles maintained their structural integrity, and no significant distortion was observed.

2) Test bundle dimensional changes were within the requirements specified for the CANFLEX fuel bundle.

3) Both test bundles passed through the kinked tube gauge.

4) Visual inspection of the test bundles showed no significant bearing pad wear, or marking of the fuel elements end caps.

7. REFERENCES

[1] P. Alavi, K. S. Sim, "Tests for CANFLEX Fuel Bundle Strength" CFXX-37100-400-003, CANFLEX-089, Rev. 0, Test Specification, March 1994.

[2] M. Gabbani, P. Alavi and S. K. Sim, "CANFLEX Natural Uranium Fuel Bundle", CFXX-37000-TS-001, Rev. 0, Technical Specification, June 1996.

[3] C. H. Chung, et al., "CANDU Hot Test Loop Operation Manual", FT/OM-HTL-RV1, Feb. 1995.

[4] S. K. Chang, "CANFLEX Fuel Bundle Strength Tests" KAERI/TP-CX201, CANFLEX-099, Rev. 0, Test Procedure, May 1995.

[5] Fuel Bundle Design Drawing, " Joint AECL-KAERI CANFLEX 43 Element Bundle (CANDU-6) Reference Drawing," CANFLEX-37000-1-1-GA-E, Rev. 03, KAERI/AECL, January 30, 1996.

Table 1. Measurement Devices for Strength Tests

Parameter	Model/Serial No.	Range
Flow Rate	Rosemount M3051CD / 93960	0~1000" H_2O
Pressure	Rosemount M3051CG / 119264	0~13000 kPa
Temperature	RTD PT100 / 9201	0~400 ℃
Feeder to Feeder Δp	Rosemount M1151 / 1570147	0~1500 kPa
Pressure Tube Δp	Rosemount M1151 / 1570150	0~1200 kPa

Table 2. Test Conditions of Double Side-stop Strength Test

Time(min.)	Flow(kg/s)	Vel.(m/s)	Re. No.	ΔP(string)	HLC*(string)	Press.(MPa)	Temp.(℃)
0.0	39.22	11.19	352478	1404.347	23.706	11.19	122.4
2.0	39.19	11.18	352196	1403.238	23.730	11.71	122.4
4.0	39.26	11.20	352678	1405.754	23.691	11.59	122.3
6.0	39.22	11.18	351751	1402.587	23.687	11.90	122.2
8.0	39.11	11.15	350326	1402.301	23.816	11.79	122.0
10.0	39.22	11.18	350788	1405.166	23.737	11.82	121.9
12.0	39.33	11.21	351274	1405.041	23.603	11.64	121.7
14.0	39.31	11.20	350615	1402.279	23.590	11.69	121.5
15.0	39.09	11.14	348559	1402.823	23.864	11.78	121.5

* Head Loss Coefficient

Table 3. Element Length Measurements for Bundle KF9414

BUNDLE LENGTH

Bundle Strength Tests — Bundle # KF9414

Element	Element Length Over End Plates in mm			Remark
	Before Test	After Test	Change	
1	0.003(Ref.=495.38)	-.003(Ref.=495.36)	-.026	
2	-.209	-.210	-.021	
3	-.164	-.167	-.023	
4	0.023	-.034	-.077	
5	-.272	-.247	0.005	
6	-.071	-.082	-.031	
7	-.111	-.194	-.103	MAX.
8	-.223	-.176	0.027	
9	-.183	-.162	0.001	
10	-.153	-.126	0.007	
11	-.254	-.215	0.019	
12	-.205	-.167	0.018	
13	-.065	-.053	-.008	
14	-.115	-.098	-.003	
15	-.081	-.079	-.018	
16	0.004	-.076	-.100	
17	-.123	-.144	-.011	
18	-.035	-.019	-.004	
19	0.011	-.040	-.071	
20	-.082	-.099	-.037	
21	-.142	-.142	-.020	
22	0.007	-.029	-.035	
23	-.094	-.112	-.038	
24	-.075	-.088	-.033	
25	-.148	-.152	-.024	
26	-.044	-.059	-.035	
27	-.113	-.115	-.022	
28	-.060	-.066	-.026	
29	-.114	-.118	-.024	
30	-.072	-.093	-.041	
31	-.062	-.088	-.046	
32	0.004	-.027	-.051	
33	-.040	-.077	-.057	
34	0.020	-.009	-.049	
35	-.038	-.053	-.095	
36	-.082	-.108	-.046	
37	-.079	-.096	-.037	
38	-.102	-.113	-.031	
39	-.117	-.140	-.043	
40	-104	-.130	-.046	
41	-.069	-.102	-.053	
42	-.067	-.084	-.037	
43	-.069	-.098	-.049	

Data recorded by J. Y. Yeon date Sept. 29 1994(Before Test), June 30 1995(After Test)
Equipment/apparatus Linear Gauge
Measuring procedure ① Put the test bundle to plain die
② Locate the tip of dial indicator to the center of the one end of the rod #1 and set "0"
③ Move the tip to the next position and measure the relative waviness along the rod number on the both end plates
④ Subtract the waviness for each rod number

Table 4. End Plate Profile of Bundle KF9414 on Marked End
(Page 1 of 2)

END PLATE PROFILE

Bundle Strength Tests - Bundle # KF9414 / Marked End

Element	Deviations from '0' Ref. in mm			Remark
	Before Test	After Test	Change	
1	0.003(REF.)	-.001(REF.)	-.004	
s	0.046	0.039	-.007	
2	-.108	-.040	0.068	
s	0.024	0.091	0.067	
3	-.069	0.030	0.099	
s	0.073	0.139	0.066	
4	0.037	0.080	0.043	
s	0.011	0.012	0.001	
5	-.152	-.120	0.032	
s	0.051	0.188	0.137	
6	0.032	0.212	0.180	
s	0.118	0.249	0.131	
7	-.025	0.103	0.128	
s	0.035	-.051	-.086	
8	-.087	-.307	-.220	
s	0.048	-.216	-.264	
9	-.026	-.320	-.294	
s	0.076	-.226	-.302	
10	-.028	-.346	-.318	
s	0.032	-.286	-.318	
11	-.065	-.382	-.317	
s	0.056	-.247	-.303	
12	-.028	-.324	-.296	
s	0.098	-.179	-.277	
13	0.035	-.245	-.280	
s	0.075	-.183	-.258	
14	-.031	-.252	-.221	
s	0.079	-.023	-.102	
15	0.001	0.008	0.007	
s	0.116	0.198	0.082	
16	0.027	0.204	0.177	
s	0.063	0.257	0.194	
17	-.048	0.226	0.274	
s	0.071	0.261	0.190	
18	-.017	0.138	0.155	
s	0.108	0.256	0.148	
19	0.005	0.169	0.164	
s	0.034	0.186	0.152	
20	-.059	0.110	0.169	
s	0.029	0.137	0.108	
21	-.089	-.038	0.051	
s	0.061	0.081	0.020	
s 2-22	0.088	-.043	-.131	
s 5-24	0.046	-.108	-.154	
s 8-26	0.081	-.172	-.253	
s 11-28	0.115	-.208	-.323	
s 14-30	0.127	-.146	-.273	
s 17-32	0.131	0.031	-.100	
s 20-34	0.132	0.026	-.106	
22	-.020	-.313	-.293	
s	0.095	-.182	-.277	
23	0.037	-.275	-.312	
s	0.084	-.243	-.327	
24	-.056	-.374	-.318	

Table 4. End Plate Profile of Bundle KF9414 on Marked End
(Page 2 of 2)

END PLATE PROFILE

Bundl Strength Tests - Bundle # KF9414 / Marked End

Element	Deviations from '0' Ref. in mm			Remark
	Before Test	After Test	Change	
s	0.090	-.240	-.330	
25	0.035	-.319	-.354	
s	0.107	-.261	-.368	
26	-.023	-.398	-.375	
s	0.130	-.264	-.394	MAX.
27	0.055	-.330	-.385	
s	0.115	-.266	-.381	
28	-.010	-.372	-.362	
s	0.136	-.213	-.349	
29	0.071	-.267	-.338	
s	0.117	-.211	-.328	
30	-.015	-.346	-.331	
s	0.155	-.178	-.333	
31	0.083	-.238	-.321	
s	0.124	-.201	-.325	
32	-.017	-.324	-.307	
s	0.138	-.183	-.321	
33	0.061	-.259	-.320	
s	0.115	-.196	-.311	
34	-.015	-.305	-.290	
s	0.130	-.156	-.286	
35	0.059	-.240	-.299	
s	0.112	-.189	-.301	
s 23-36	0.136	-.198	-.334	
s 25-37	0.141	-.217	-.358	
s 27-38	0.156	-.224	-.380	
s 29-39	0.157	-.184	-.341	
s 31-40	0.159	-.172	-.331	
s 33-41	0.158	-.172	-.330	
s 35-42	0.147	-.166	-.313	
36	0.027	-.321	-.348	
s	0.116	-.229	-.345	
37	0.017	-.339	-.356	
s	0.113	-.242	-.355	
38	0.026	-.335	-.361	
s	0.121	-.246	-.367	
39	0.019	-.333	-.352	
s	0.109	-0237	-.346	
40	0.013	-.329	-.342	
s	0.128	-.208	-.336	
41	0.023	-.318	-.341	
s	0.130	-.208	-.338	
42	0.036	-.297	-.333	
s	0.129	-.207	-.336	
s 37-43	0.133	-.225	-.358	
41-43	0.153	-.181	-.334	
43	0.054	-.297	-.351	

Data recorded by I. Y. Yeon date Sept. 29 1994(Before Test), June 30 1995(After Test)
Equipment/apparatus Linear Gauge
Measuring procedure ① Put the test bundle to plain die
② Locate the tip of dial indicator to the center of the one end of the rod #1 and set "0"
③ Move the tip to the next position and measure the relative waviness along the rod number on the end plate

Table 5. End Plate Profile of Bundle KF9414 on Plain End
(Page 1 of 2)

END PLATE PROFILE

Bundle Strength Tests — Bundle # KF9414 / Plain End

Element	Deviations from '0' Ref. in mm			Remark
	Before Test	After Test	Change	
1	0.000(REF.)	-.002(REF.)	-.002	
s	0.019	0.001	-.018	
2	-.101	-.170	-.069	
s	0.007	-.082	-.089	
3	-.095	-.197	-.102	
s	0.046	-.055	-.101	
4	-.014	-.114	-.100	
s	0.010	-.034	-.044	
5	-.120	-.127	-.007	
s	0.000	-.130	-.130	
6	-.103	-.294	-.191	
s	0.005	-.203	-.208	
7	-.086	-.297	-.211	
s	-.032	0.053	0.085	
8	-.136	0.131	0.267	
s	-.030	0.252	0.282	
9	-.157	0.158	0.315	
s	-.037	0.289	0.326	
10	-.125	0.220	0.345	
s	-.079	0.260	0.339	
11	-.189	0.167	0.356	
s	-.067	0.268	0.335	
12	-.177	0.157	0.334	
s	-.040	0.267	0.307	
13	-.100	0.192	0.292	
s	-.006	0.244	0.250	
14	-.084	0.154	0.238	
s	0.023	0.099	0.076	
15	-.082	-.087	-.005	
s	0.044	-.113	-.157	
16	-.023	-.280	-.257	
s	0.039	-.290	-.329	
17	-.075	-.370	-.295	
s	0.056	-.174	-.230	
18	-.018	-.157	-.139	
s	0.093	-.115	-.208	
19	0.006	-.209	-.215	
s	0.077	-.135	-.212	
20	-.023	-.209	-.186	
s	0.074	-.052	-.126	
21	-.053	-.104	-.051	
s	0.064	0.042	-.022	
s 2-22	0.114	0.226	0.112	
s 5-24	0.084	0.210	0.126	
s 8-26	0.074	0.383	0.309	
s 11-28	0.043	0.393	0.350	
s 14-30	0.074	0.341	0.267	
s 17-32	0.124	0.072	-.052	
s 20-34	0.153	0.153	0.000	
22	0.027	0.284	0.257	
s	0.063	0.331	0.268	
23	-.131	0.163	0.294	
s	0.009	0.304	0.295	
24	-.019	0.286	0.305	

Table 5. End Plate Profile of Bundle KF9414 on Plain End
(Page 2 of 2)

END PLATE PROFILE

Bundle Strength Tests

Bundle # KF9414 / Plain End

Element	Deviations from '0' Ref. in mm			Remark
	Before Test	After Test	Change	
s	0.016	0.336	0.320	
25	-.183	0.167	0.350	
s	-.041	0.322	0.363	
26	-.021	0.339	0.360	
s	0.024	0.406	0.382	
27	-.168	0.215	0.383	MAX.
s	-.047	0.334	0.381	
28	-.050	0.306	0.356	
s	-.001	0.338	0.339	
29	-.185	0.149	0.334	
s	-.037	0.293	0.330	
30	-.057	0.253	0.310	
s	0.025	0.314	0.289	
31	-.148	0.150	0.298	
s	0.014	0.304	0.290	
32	0.021	0.297	0.276	
s	0.074	0.342	0.268	
33	-.101	0.182	0.283	
s	0.031	0.320	0.289	
34	0.035	0.296	0.261	
s	0.093	0.354	0.261	
35	-.097	0.187	0.284	
s	0.021	0.284	0.263	
s 23-36	0.031	0.343	0.312	
s 25-37	0.029	0.363	0.334	
s 27-38	0.003	0.368	0.365	
s 29-39	0.006	0.332	0.326	
s 31-40	0.039	0.333	0.294	
s 33-41	0.077	0.364	0.287	
s 35-42	0.062	0.346	0.284	
36	-.109	0.213	0.322	
s	0.016	0.334	0.318	
37	-.096	0.243	0.339	
s	0.002	0.351	0.349	
38	-.128	0.222	0.350	
s	-.031	0.313	0.344	
39	-.136	0.193	0.329	
s	-.025	0.305	0.330	
40	-.117	0.199	0.316	
s	0.015	0.336	0.321	
41	-.092	0.216	0.308	
s	0.019	0.330	0.311	
42	-.103	0.213	0.316	
s	0.016	0.326	0.310	
s 37-43	-.002	0.323	0.325	
s 41-43	-.001	0.315	0.316	
43	-.123	0.199	0.322	

Data recorded by I. Y. Yeon date Sept. 29 1994(Before Test), June 30 1995(After Test)
Equipment/apparatus Linear Gauge
Measuring procedure ① Put the test bundle to plain die
② Locate the tip of dial indicator to the center of the one end of the rod #1 and set "0"
③ Move the tip to the next position and measure the relative waviness along the rod number on the end plate

Table 6. Sheath Distortion of Bundle KF9414 on Marked End

SHEATH DISTORTION

Bundle Strength Tests

Bundle # KF9414 / Marked End

Element	Maximum Distortion of Each Outside Element in mm			Remark
	Before Test	After Test	Change	
1	-.068	-.106	-.018	
2	0.048	0.042	-.006	
3	0.061	0.071	0.010	
4	-.039	0.055	0.094	
5	0.056	0.044	-.012	
6	0.053	0.043	-.010	
7	-.060	-.075	-.015	
8	0.053	0.064	0.011	
9	-.035	-.068	-.033	
10	-.057	-.068	-.011	
11	0.022	-.052	-.074	
12	0.041	0.048	0.007	
13	-.084	-.095	-.011	
14	0.057	0.057	0.000	
15	-.056	-.054	0.002	
16	-.039	0.056	0.095	
17	0.040	-.086	-.126	MAX.
18	0.049	0.060	0.011	
19	0.046	0.067	0.021	
20	0.046	0.060	0.014	
21	0.041	0.040	-.001	

* Profiles of each outside element for a distance of approximately 12 mm from the end cap along the element sheath.

Data recorded by S. M. Choi date Sept. 29 1994(Before Test), June 30 1995(After Test)
Equipment/apparatus Height Gauge
Measuring procedure ① Put the test bundle to plain die and rotate the bundle for measuring rod on top position
② Locate the tip of dial indicator to the rod end(0.3mm apart from the connection of the rod and end cap) and set "0"
③ Move the tip to the next 2mm inner position and measure the relative waviness along the rod on the both end plates
④ Take the largest value among the measured 7 positions for each sides

Table 7. Sheath Distortion of Bundle KF9414 on Plain End

SHEATH DISTORTION

Bundle Strength Tests

Bundle # KF9414 / Plain End

Element	Maximum Distortion of Each Outside Element in mm			Remark
	Before Test	After Test	Change	
1	-.074	-.083	-.009	
2	0.058	-.059	-.117	
3	0.033	-.059	-.092	
4	-.050	-.151	-.101	
5	0.058	0.056	-.002	
6	0.060	0.056	-.004	
7	0.039	-.198	-.237	MAX.
8	0.041	0.047	0.006	
9	-.037	0.042	0.079	
10	0.045	0.054	0.009	
11	0.049	0.041	-.008	
12	-.058	-.086	-.028	
13	0.033	-.058	-.091	
14	0.054	0.055	0.001	
15	-.064	-.057	0.007	
16	-.050	-.147	-.097	
17	0.050	-.143	-.193	
18	-.054	-.045	0.009	
19	0.056	-.090	-.146	
20	0.054	-.089	-.143	
21	-.045	-.059	-.014	

* Profiles of each outside element for a distance of approximately 12 mm from the end cap along the element sheath.

Data recorded by S. M. Choi date Sept. 29 1994(Before Test), June 30 1995(After Test)
Equipment/apparatus Height Gauge
Measuring procedure ① Put the test bundle to plain die and rotate the bundle for measuring rod on top position
② Locate the tip of dial indicator to the rod end(0.3mm apart from the connection of the rod and end cap) and set "0"
③ Move the tip to the next 2mm inner position and measure the relative waviness along the rod on the both end plates
④ Take the largest value among the measured 7 positions for each sides

Table 8. Element Bow Measurements for Bundle KF9414 in X-Position

OUTER ELEMENT BOW

Bundle Strength Tests

Bundle # KF9414 / X-position

Element	Maximum Bow of Each Outside Element in mm			Remark
	Before Test	After Test	Change	
1	-.33	-.30	0.03	
2	0.06	-.25	-.31	
3	0.10	-.07	-.17	
4	-.13	-.24	-.11	
5	0.13	-.13	-.26	
6	-.03	-.25	-.22	
7	-.29	-.34	-.05	
8	0.11	-.21	-.32	
9	-.09	-.24	-.15	
10	-.26	-.34	-.08	
11	0.05	-.20	-.25	
12	-.09	-.20	-.11	
13	-.26	-.27	-.01	
14	-.07	-.19	-.12	
15	-.18	-.17	0.01	
16	-.31	-.35	-.04	
17	-.05	-.49	-.44	MAX.
18	-.12	-.23	-.11	
19	-.28	-.35	-.07	
20	0.11	-.22	-.33	
21	-.18	-.19	-.01	

Data recorded by S. M. Choi date Sept. 29 1994(Before Test), June 30 1995(After Test)
Equipment/apparatus Height Gauge
Measuring procedure ① Put the test bundle to plain die and rotate the bundle for measuring rod on top position (X-position)
② Locate the tip of dial indicator to the rod end and set "0"
③ Move the tip to the next position and measure the relative waviness along the rod
④ Take the largest value among the measured 10 positions for each rods

Table 9. Element Bow Measurements for Bundle KF9414 in Y-Position

OUTER ELEMENT BOW

Bundle Strength Tests

Bundle # KF9414 / Y-position

Element	Maximum Bow of Each Outside Element in mm			Remark
	Before Test	After Test	Change	
1	0.39	-.25	-.64	
2	0.33	-.33	-.66	MAX.
3	0.36	0.37	0.01	
4	0.40	0.36	-.04	
5	0.43	0.43	0.00	
6	0.30	0.34	0.04	
7	0.37	0.31	-.06	
8	0.43	0.38	-.05	
9	0.41	0.39	-.02	
10	0.39	0.26	-.13	
11	0.36	-.26	-.62	
12	0.39	0.33	-.06	
13	0.39	0.32	-.07	
14	0.39	0.24	-.15	
15	0.37	0.34	-.03	
16	0.34	0.35	0.01	
17	0.38	0.32	-.06	
18	0.35	0.24	-.11	
19	0.36	0.24	-.12	
20	0.37	0.26	-.11	
21	0.34	0.26	-.08	

Data recorded by S. M. Choi date Sept. 29 1994(Before Test), June 30 1995(After Test)
Equipment/apparatus Height Gauge
Measuring procedure ① Put the test bundle to plain die and rotate the bundle for measuring rod on horizontal position (Y-position)
② Locate the tip of dial indicator to the rod end and set "0"
③ Move the tip to the next position and measure the relative waviness along the rod
④ Take the largest value among the measured 10 positions for each rods

Table 10. Minimum Clearance Measurements between Outer Elements of Bundle KF9414

MINIMUM CLEARANCE BETWEEN OUTER ELEMENTS

Bundle Strength Tests — Bundle # KF9414

Location	Minimum Clearance between Outer Elements in mm			Remark
	Before Test	After Test	Change	
1-2	1.65	1.65	0.00	
2-3	1.61	1.64	0.03	
3-4	1.63	1.64	0.01	
4-5	1.69	1.72	0.03	
5-6	1.55	1.57	0.02	
6-7	1.62	1.61	-.01	
7-8	1.66	1.65	-.01	
8-9	1.59	1.62	0.03	
9-10	1.62	1.63	0.01	
10-11	1.65	1.68	0.03	
11-12	1.61	1.64	0.03	
12-13	1.60	1.62	0.02	
13-14	1.65	1.69	0.04	
14-15	1.62	1.64	0.02	
15-16	1.63	1.64	0.01	
16-17	1.66	1.65	-.01	
17-18	1.61	1.63	0.02	
18-19	1.61	1.65	0.04	
19-20	1.66	1.65	-.01	
20-21	1.59	1.60	0.01	
21-1	1.65	1.60	-.05	MAX.

Data recorded by S. M. Choi date Sept. 29 1994(Before Test), June 30 1995(After Test)
Equipment/apparatus Bore Gauge
Measuring procedure ① Put the test bundle to plain die and rotate the bundle for measuring rod clearance on top position
② Insert the conical tip of dial indicator to the rod clearance at 3 mm apart from the end cap connection at marked end side
③ Rotate the test bundle for measuring next rod clearance on top position and measure the clearance

Table 11. Π-tape Measurement and Kinked Tube Gauge Test Results of Bundle KF9414

Π TAPE MEASUREMENT AND KINKED TUBE GAUGE TEST RESULTS

Bundle Strength Tests - Bundle # KF9414

Inspection		Before Test	After Test	Remark
Π-Tape Measurement (mm)	Marked End	101.80	101.82	
	Center	-	-	
	Plain End	101.83	101.68	
Kinked Tube Gauge Test		Passed	Passed	

Data recorded by I. Y. Yeon date Sept. 29 1994(Before Test), June 30 1995(After Test)
Equipment/apparatus Π-tape, Kinked Tube
Measuring procedure ① Stand the test bundle to plain die
② Measure the diameter of the bundle for three positions(marked end, center, plain end) with Π-tape
③ Pass the bundle to kinked tube

Table 12 Test Conditions of Single Side-stop Strength Test

Time(min.)	Flow(kg/s)	Vel.(m/s)	Re. No.	△P(string)	HLC*(string)	Press.(MPa)	Temp.(℃)
0.0	32.54	9.28	290528	866.788	21.278	11.36	121.6
2.0	32.48	9.26	289826	865.433	21.329	11.61	121.6
4.0	32.49	9.26	289883	864.529	21.291	11.55	121.6
6.0	32.53	9.27	290166	866.039	21.267	11.56	121.5
8.0	32.53	9.27	289933	865.749	21.269	11.48	121.5
10.0	32.53	9.27	289819	865.003	21.243	11.35	121.4
12.0	32.47	9.25	288973	862.281	21.266	11.53	121.3
14.0	32.48	9.26	289022	864.037	21.290	11.33	121.2
15.0	32.53	9.27	289262	866.660	21.296	11.41	121.2

* Head Loss Coefficient

Table 13. Element Length Measurements for Bundle KF9426

BUNDLE LENGTH

Bundle Strength Tests — Bundle # KF9426

Element	Element Length Over End Plates in mm			Remark
	Before Test	After Test	Change	
1	-.001(Ref.=495.46)	-.006(Ref.=495.36)	-.105	
2	0.006	0.002	-.104	
3	0.040	0.050	-.090	
4	0.074	0.090	-.084	
5	-.101	-.075	-.074	
6	0.049	0.087	-.062	
7	-.004	0.022	-.074	
8	0.111	0.215	0.004	
9	0.132	0.175	-.057	
10	0.147	0.188	-.059	
11	0.032	0.092	-.040	
12	0.081	0.115	-.066	
13	0.136	0.137	-.099	
14	0.025	0.018	-.107	
15	0.147	0.140	-.107	
16	0.192	0.111	-.181	MAX.
17	0.119	0.062	-.157	
18	0.161	0.164	-.097	
19	0.049	0.007	-.142	
20	-.093	-.113	-.120	
21	-.046	-.053	-.107	
22	0.041	0.023	-.118	
23	-.016	-.016	-.100	
24	-.027	-.020	-.093	
25	-.043	-.030	-.087	
26	-.049	-.032	-.083	
27	-.142	-.138	-.096	
28	-.055	-.059	-.104	
29	-.257	-.273	-.116	
30	-.065	-.090	-.125	
31	-.128	-.144	-.116	
32	-.042	-.030	-.088	
33	-.048	-.067	-.119	
34	-.006	-.007	-.101	
35	-.049	-.036	-.087	
36	-.011	-.009	-.098	
37	-.078	-.062	-.084	
38	-.057	-.046	-.089	
39	-.071	-.080	-.109	
40	-.006	-.017	-.111	
41	-.064	-.068	-.104	
42	-.074	-.057	-.083	
43	-.060	-.063	-.103	

Data recorded by I. Y. Yeon date Sept. 29 1994(Before Test), June 30 1995(After Test)
Eequipment/apparatus Linear Gauge
Measuring procedure ① Put the test bundle to plain die
② Locate the tip of dial indicator to the center of the one end of the rod #1 and set "0"
③ Move the tip to the next position and measure the relative waviness along the rod number on the both end plates
④ Subtract the waviness for each rod number

Table 14. End Plate Profile of Bundle KF9426 on Marked End
(Page 1 of 2)

END PLATE PROFILE

Bundle Strength Tests

Bundle # KF9426 / Marked End

Location	Deviations from '0' Ref. in mm			Remark
	Before Test	After Test	Change	
1	0.000(REF.)	-.003(REF.)	-.003	
s	0.093	0.038	-.055	
2	0.037	-.006	-.043	
s	0.127	0.081	-.046	
3	0.067	0.023	-.044	
s	0.140	0.100	-.040	
4	0.060	0.018	-.042	
s	0.089	0.029	-.060	
5	0.007	-.021	-.028	
s	0.171	0.151	-.020	
6	0.128	0.114	-.014	
s	0.191	0.181	-.010	
7	0.076	0.052	-.024	
s	0.187	0.164	-.023	
8	0.163	0.145	-.018	
s	0.226	0.211	-.015	
9	0.148	0.137	-0.11	
s	0.218	0.216	-.002	
10	0.148	0.154	0.006	
s	0.165	0.180	0.015	
11	0.107	0.126	0.019	
s	0.188	0.200	0.012	
12	0.116	0.121	0.005	
s	0.193	0.189	-.004	
13	0.129	0.121	-.008	
s	0.162	0.130	-.032	
14	0.081	0.081	0.000	
s	0.175	0.216	0.041	
15	0.136	0.234	0.098	
s	0.205	0.394	0.189	
16	0.134	0.425	0.291	
s	0.150	0.423	0.273	
17	0.106	0.401	0.295	MAX.
s	0.170	0.414	0.244	
18	0.096	0.325	0.229	
s	0.125	0.358	0.233	
19	0.014	0.276	0.262	
s	0.017	0.275	0.258	
20	-.073	0.205	0.278	
s	0.048	0.285	0.237	
21	-.021	0.190	0.211	
s	0.037	0.183	0.146	
s 2-22	0.266	0.190	-.076	
s 5-24	0.138	0.094	-.044	
s 8-26	0.222	0.192	-.030	
s 11-28	0.198	0.192	-.006	
s 14-30	0.183	0.166	-.017	
s 17-32	0.186	0.301	0.115	
s 20-34	0.109	0.217	0.108	
22	-.016	-.085	-.069	
s	0.137	0.088	-.049	
23	0.035	-.017	-.052	
s	0.086	0.034	-.052	
24	-.025	-.068	-.043	

Table 14. End Plate Profile of Bundle KF9426 on Marked End
(Page 2 of 2)

END PLATE PROFILE

Bundle Strength Tests — Bundle # KF9426 / Marked End

Element	Deviations from '0' Ref. in mm			Remark
	Before Test	After Test	Change	
s	0.143	0.089	-.054	
25	0.103	0.066	-.037	
s	0.177	0.143	-.034	
26	0.078	0.050	-.028	
s	0.148	0.127	-.021	
27	0.021	-.011	-.032	
s	0.084	0.073	-.011	
28	0.059	0.034	-.025	
s	0.097	0.061	-.036	
29	-.068	-.100	-.032	
s	0.031	0.024	-.007	
30	0.064	0.027	-.037	
s	0.129	0.097	-.032	
31	0.012	-.014	-.026	
s	0.084	0.082	-.002	
32	0.032	0.023	-.009	
s	0.111	0.098	-.013	
33	0.013	-.008	-.021	
s	0.094	0.080	-.014	
34	0.039	0.026	-.013	
s	0.103	0.080	-.023	
35	-.002	-.042	-.040	
s	0.049	0.002	-.047	
s 23-36	0.133	0.089	-.044	
s 25-37	0.183	0.152	-.031	
s 27-38	0.145	0.108	-.037	
s 29-39	0.108	0.073	-.035	
s 31-40	0.149	0.114	-.035	
s 33-41	0.128	0.098	-.030	
s 35-42	0.108	0.061	-.047	
36	0.031	-.014	-.045	
s	0.120	0.076	-.044	
37	0.010	-.018	-.028	
s	0.135	0.103	-.032	
38	0.054	0.025	-.029	
s	0.137	0.101	-.036	
39	0.039	0.001	-.038	
s	0.126	0.107	-.019	
40	0.080	0.043	-.037	
s	0.146	0.108	-.038	
41	0.003	-.029	-.032	
s	0.101	0.066	-.035	
42	0.005	-.028	-.033	
s	0.097	0.063	-.034	
s 37-43	0.115	0.079	-.036	
s 41-43	0.151	0.104	-.047	
43	0.048	-.002	-.050	

Data recorded by J. Y. Yeon date Sept. 29 1994(Before Test), June 30 1995(After Test)
Equipment/apparatus Linear Gauge
Measuring procedure ① Put the test bundle to plain die
② Locate the tip of dial indicator to the center of the one end of the rod #1 and set "0"
③ Move the tip to the next position and measure the relative waviness along the rod number on the end plate

Table 15. End Plate Profile of Bundle KF9426 on Plain End
(Page 1 of 2)

END PLATE PROFILE

Bundle Strength Tests

Bundle # KF9426 / Plain End

Element	Deviations from '0' Ref. in mm			Remark
	Before Test	After Test	Change	
1	-.001(REF.)	-.003(REF.)	-.002	
s	0.053	0.086	0.033	
2	-.031	0.008	0.039	
s	0.062	0.114	0.052	
3	-.027	0.027	0.054	
s	0.091	0.145	0.054	
4	0.014	0.072	0.058	
s	0.030	0.087	0.057	
5	-.108	-.054	0.054	
s	0.012	0.059	0.047	
6	-.079	-.027	0.052	
s	0.016	0.048	0.032	
7	-.080	-.030	0.050	
s	-.010	0.057	0.067	
8	-.062	0.070	0.122	
s	0.068	0.068	0.000	
9	-.016	0.038	0.054	
s	0.080	0.104	0.024	
10	-.001	0.034	0.035	
s	0.014	0.039	0.025	
11	-.075	-.034	0.041	
s	0.091	0.078	-.013	
12	-.035	-.006	0.029	
s	0.066	0.092	0.026	
13	0.007	0.016	0.009	
s	0.035	0.030	-.005	
14	-.056	-.063	-.007	
s	0.073	-.003	-.076	
15	0.011	-.094	-.105	
s	0.119	-.193	-.312	
16	0.058	-.314	-.372	
s	0.110	-.270	-.380	MAX.
17	0.013	-.339	-.352	
s	0.138	-.149	-.287	
18	0.065	-.161	-.226	
s	0.138	-.161	-.299	
19	0.035	-.269	-.304	
s	0.084	-.235	-.319	
20	-.020	-.318	-.298	
s	0.084	-.184	-.268	
21	-.025	-.243	-.218	
s	0.074	-.037	-.111	
s 2-22	0.184	0.232	0.048	
s 5-24	0.090	0.145	0.055	
s 8-26	0.040	0.095	0.055	
s 11-28	0.053	0.089	0.036	
s 14-30	0.067	0.071	0.004	
s 17-32	0.140	-.092	-.232	
s 20-34	0.134	-.039	-.173	
22	0.057	0.108	0.051	
s	0.120	0.163	0.043	
23	-.051	0.001	0.052	
s	0.055	0.110	0.055	
24	-.002	0.048	0.050	

Table 15. End Plate Profile of Bundle KF9426 on Plain End
(Page 2 of 2)

END PLATE PROFILE

Bundle Strength Tests

Bundle # KF9426 / Plain End

Element	Deviations from '0' Ref. in mm			Remark
	Before Test	After Test	Change	
s	0.028	0.072	0.044	
25	-.146	-.096	0.050	
s	-.062	-.005	0.057	
26	-.127	-.082	0.045	
s	-.038	0.000	0.038	
27	-.163	-.127	0.036	
s	-.081	-.036	0.045	
28	-.114	-.093	0.021	
s	-.059	-.028	0.031	
29	-.189	-.173	0.016	
s	-.096	-.067	0.029	
30	-.129	-.117	0.012	
s	-.016	-.014	0.002	
31	-.140	-.130	0.010	
s	-.037	-.041	-.004	
32	-.074	-.053	0.021	
s	0.042	0.048	0.006	
33	-.061	-.059	0.002	
s	0.025	0.027	0.002	
34	-.045	-.033	0.012	
s	0.067	0.090	0.023	
35	-.047	0.006	0.053	
s	0.082	0.125	0.043	
s 23-36	0.084	0.134	0.050	
s 25-37	0.028	0.071	.0.043	
s 27-38	0.001	0.032	0.031	
s 29-39	-.008	0.013	0.021	
s 31-40	0.026	0.030	0.004	
s 33-41	0.085	0.098	0.013	
s 35-42	0.095	0.143	0.048	
36	-.042	0.005	0.047	
s	0.052	0.092	0.040	
37	-.088	-.044	0.044	
s	0.007	0.042	0.035	
38	-.111	-.071	0.040	
s	-.016	0.008	0.024	
39	-.110	-.081	0.029	
s	-.005	0.022	0.027	
40	-.086	-.060	0.026	
s	0.030	0.048	0.018	
41	-.067	-.039	0.028	
s	0.033	0.060	0.027	
42	-.079	-.029	0.050	
s	0.047	0.092	0.045	
s 37-43	0.006	0.038	0.032	
s 41-43	0.007	0.036	0.029	
43	-.108	-.061	0.047	

Data recorded by I. Y. Yeon date Sept. 29 1994(Before Test), June 30 1995(After Test)
Equipment/apparatus Linear Gauge
Measuring procedure ① Put the test bundle to plain die
② Locate the tip of dial indicator to the center of the one end of the rod #1 and set "0"
③ Move the tip to the next position and measure the relative waviness along the rod number on the end plate

Table 16. Sheath Distortion of Bundle KF9426 on Marked End

SHEATH DISTORTION

Bundle Strength Tests

Bundle # KF9426 / Marked End

Element	Maximum Distortion of Each Outside Element in mm			Remark
	Before Test	After Test	Change	
1	-.094	-.60	-.506	MAX.
2	0.035	-.19	-.225	
3	-.050	-.29	-.240	
4	-.070	-.37	-.300	
5	0.094	0.22	0.126	
6	0.036	-.13	-.166	
7	-.109	-.52	-.411	
8	-.060	-.35	-.290	
9	-.047	-.27	-.223	
10	-.080	-.47	-.390	
11	0.044	0.09	0.046	
12	-.051	-.30	-.249	
13	-.081	-.49	-.409	
14	0.038	-.18	-.218	
15	0.036	-.19	-.226	
16	-.063	-.20	-.137	
17	-.048	-.31	-.262	
18	0.062	-.11	-.172	
19	-.086	-.41	-.324	
20	0.077	0.12	0.043	
21	0.036	-.29	-.326	

* Profiles of each outside element for a distance of approximately 12 mm from the end cap along the element sheath.

Data recorded by S. M. Choi date Sept. 29 1994(Before Test), June 30 1995(After Test)
Equipment/apparatus Height Gauge
Measuring procedure ① Put the test bundle to plain die and rotate the bundle for measuring rod on top position
② Locate the tip of dial indicator to the rod end(0.3mm apart from the connection of the rod and end cap) and set "0"
③ Move the tip to the next 2mm inner position and measure the relative waviness along the rod on the both end plates
④ Take the largest value among the measured 7 positions for each sides

Table 17. Sheath Distortion of Bundle KF9426 on Plain End

SHEATH DISTORTION

Bundle Strength Tests

Bundle # KF9426 / Plain End

Element	Maximum Distortion of Each Outside Element in mm			Remark
	Before Test	After Test	Change	
1	-.086	-.48	-.394	
2	0.047	-.20	-.247	
3	-.041	-.29	-.249	
4	0.056	-.20	-.256	
5	0.049	0.07	0.021	
6	0.050	0.17	0.120	
7	-.071	-.37	-.299	
8	0.037	-.16	-.197	
9	-.063	-.36	-.297	
10	-.066	-.40	-.334	
11	-.047	-.32	-.273	
12	-.077	-.42	-.343	
13	-.051	-.37	-.319	
14	0.062	-.15	-.212	
15	-.054	-.29	-.236	
16	0.060	-.72	-.780	
17	-.072	-.99	-.918	MAX.
18	-.071	-.37	-.299	
19	-.072	-.83	-.758	
20	0.043	-.70	-.743	
21	-.049	-.42	-.371	

* Profiles of each outside element for a distance of approximately 12 mm from the end cap along the element sheath.

Data recorded by S. M. Choi date Sept. 29 1994(Before Test), June 30 1995(After Test)
Equipment/apparatus Height Gauge
Measuring procedure ① Put the test bundle to plain die and rotate the bundle for measuring rod on top position
② Locate the tip of dial indicator to the rod end(0.3mm apart from the connection of the rod and end cap) and set "0"
③ Move the tip to the next 2mm inner position and measure the relative waviness along the rod on the both end plates
④ Take the largest value among the measured 7 positions for each sides

Table 18. Element Bow Measurements for Bundle KF9426 in X-Position

OUTER ELEMENT BOW

Bundle Strength Tests

Bundle # KF9426 / X-position

Element	Maximum Bow of Each Outside Element in mm			Remark
	Before Test	After Test	Change	
1	-.22	-.27	-.05	
2	-.20	-.17	0.03	
3	-.13	-.13	0.00	
4	-.20	-.20	0.00	
5	0.14	0.17	0.03	
6	0.20	-.19	-.39	MAX.
7	-.32	-.36	-.04	
8	-.17	-.28	-.11	
9	-.15	-.15	0.00	
10	-.18	-.24	-.06	
11	-.11	-.16	-.05	
12	-.11	-.13	-.02	
13	-.24	-.25	-.01	
14	-.04	0.08	0.12	
15	-.16	-.16	0.00	
16	-.22	-.35	-.13	
17	-.20	-.27	-.07	
18	-.07	0.14	0.21	
19	-.13	-.25	-.12	
20	0.11	-.19	-.30	
21	-.15	-.16	-.01	

Data recorded by S. M. Choi date Sept. 29 1994(Before Test), June 30 1995(After Test)
Equipment/apparatus Height Gauge
Measuring procedure ① Put the test bundle to plain die and rotate the bundle for measuring rod on top position (X-position)
② Locate the tip of dial indicator to the rod end and set "0"
③ Move the tip to the next position and measure the relative waviness along the rod
④ Take the largest value among the measured 10 positions for each rods

Table 19. Element Bow Measurements for Bundle KF9426 in Y-Position

OUTER ELEMENT BOW

Bundle Strength Tests

Bundle # KF9426 / Y-position

Element	Maximum Bow of Each Outside Element in mm			Remark
	Before Test	After Test	Change	
1	0.46	0.44	-.02	
2	0.48	0.48	0.00	
3	0.45	0.40	-.05	
4	0.43	0.43	0.00	
5	0.46	0.40	-.06	
6	0.43	0.40	-.03	
7	0.48	0.44	-.04	
8	0.48	-.22	-.70	
9	0.49	-.33	-.82	
10	0.49	-.32	-.81	
11	0.48	-.33	-.81	
12	0.41	0.29	-.12	
13	0.41	-.42	-.83	MAX.
14	0.40	-.35	-.75	
15	0.41	0.33	-.08	
16	0.39	0.44	0.05	
17	0.45	0.37	-.08	
18	0.52	0.39	-.13	
19	0.48	0.47	-.01	
20	0.47	0.43	-.04	
21	0.36	0.37	0.01	

Data recorded by S. M. Choi date Sept. 29 1994(Before Test), June 30 1995(After Test)
Equipment/apparatus Height Gauge
Measuring procedure ① Put the test bundle to plain die and rotate the bundle for measuring rod on horizontal position (Y-position)
② Locate the tip of dial indicator to the rod end and set "0"
③ Move the tip to the next position and measure the relative waviness along the rod
④ Take the largest value among the measured 10 positions for each rods

Table 20. Minimum Clearance Measurements between Outer Elements of Bundle KF9426

MINIMUM CLEARANCE BETWEEN OUTER ELEMENTS

Bundle Strength Tests — Bundle # KF9426

Location	Minimum Clearance between Outer Elements in mm			Remark
	Before Test	After Test	Change	
1-2	1.61	1.615	0.005	
2-3	1.60	1.605	0.005	
3-4	1.60	1.600	0.000	
4-5	1.63	1.635	0.005	
5-6	1.59	1.590	0.000	
6-7	1.62	1.630	0.010	
7-8	1.63	1.640	0.010	
8-9	1.59	1.600	0.010	
9-10	1.61	1.605	-.005	
10-11	1.62	1.625	0.005	
11-12	1.59	1.590	0.000	
12-13	1.59	1.590	0.000	
13-14	1.59	1.600	0.010	
14-15	1.62	1.635	0.015	
15-16	1.62	1.615	-.005	
16-17	1.60	1.580	-.002	
17-18	1.63	1.635	0.005	
18-19	1.59	1.610	0.020	MAX.
19-20	1.64	1.635	-.005	
20-21	1.58	1.580	0.000	
21-1	1.60	1.600	0.000	

Data recorded by S. M. Choi date Sept. 29 1994(Before Test), June 30 1995(After Test)
Equipment/apparatus Bore Gauge
Measuring procedure ① Put the test bundle to plain die and rotate the bundle for measuring rod clearance on top position
② Insert the conical tip of dial indicator to the rod clearance at 3 mm apart from the end cap connection at marked end side
③ Rotate the test bundle for measuring next rod clearance on top position and measure the clearance

Table 21. Π-tape Measurement and Kinked Tube Gauge Test Results of Bundle KF9426

Π TAPE MEASUREMENT AND KINKED TUBE GAUGE TEST RESULTS

Bundle Strength Tests — Bundle # KF9426

Inspection		Before Test	After Test	Remark
Π-Tape Measurement (mm)	Marked End	101.75	101.75	
	Center	-	101.67	
	Plain End	101.75	101.30	
Kinked Tube Gauge Test		Passed	Passed	

Data recorded by J. Y. Yeon date Sept. 29 1994(Before Test), June 30 1995(After Test)
Equipment/apparatus Π-tape, Kinked Tube
Measuring procedure
① Stand the test bundle to plain die
② Measure the diameter of the bundle for three positions(marked end, center, plain end) with Π-tape
③ Pass the bundle to kinked tube

Table 22 Maximum Changes of the Bundle Measurements

(Unit : mm)

Inspection Item \ Bundle No.		KF9426 (Single)	KF9414 (Double)
End Plate Profile	Marked	0.295	-0.394
	Plain	-0.380	0.383
Element Length		-0.181	-0.103
Sheath Distortion	Marked	-0.506	-0.126
	Plain	-0.918	-0.237
Outer Element Bow	X-position	-0.39	-0.44
	Y-position	-0.83	-0.66
Minimum Clearance between Outer Elements		0.020	-0.05
Ⅱ-tape Measurement		-0.45	-0.15
Kinked Tube Gauge Test		Passed	Passed

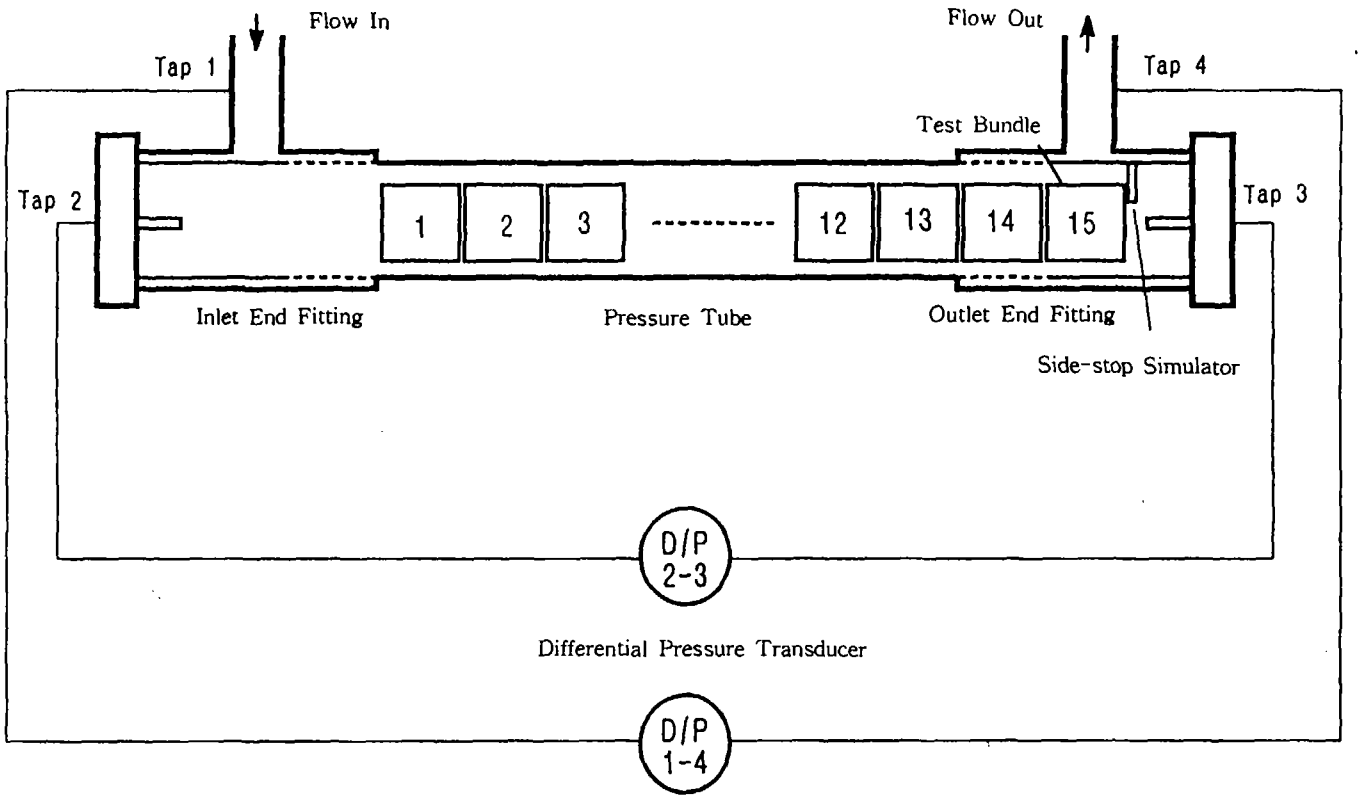


Figure 1. Schematic Diagram of Strength Test Set-up

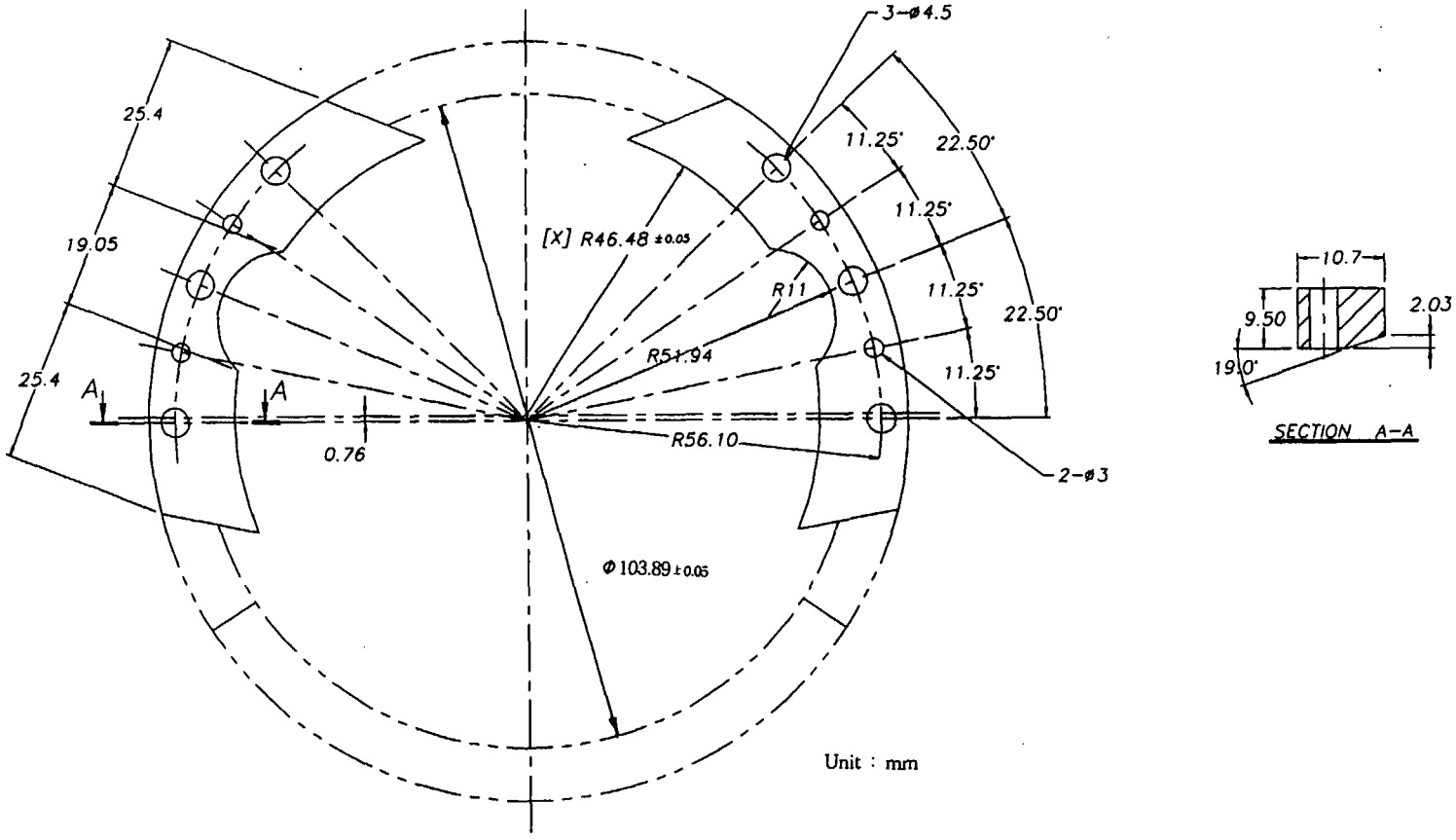
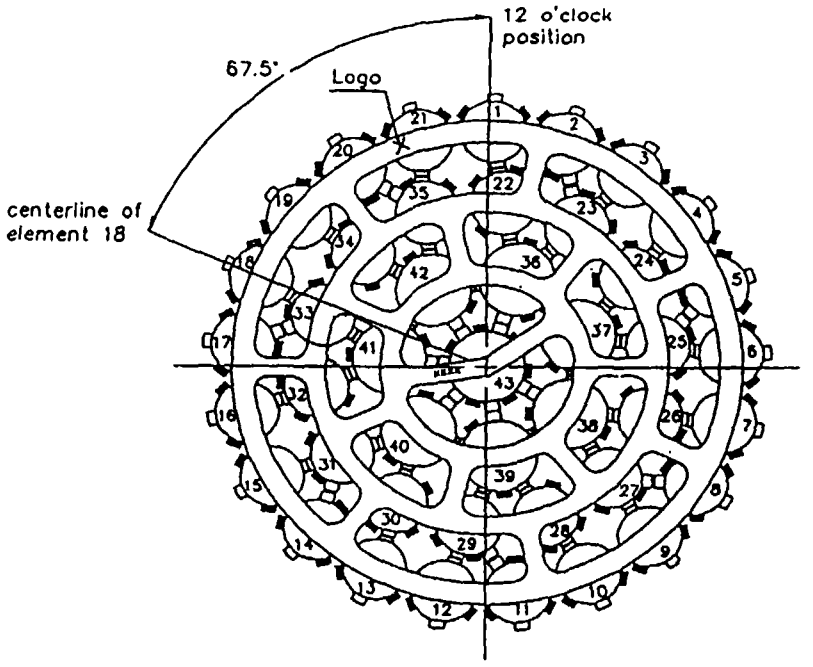


Figure 2. Fuel Machine Side-stop Simulator for CANFLEX Fuel Strength Tests



Bundle Orientations : Bundle in Position 15
Bundle in Position 14
Bundle in Position 13
Other bundles were randomly oriented.

Figure 3. Positions and Orientations of Fuel Bundles Used in Double and Single Side-stop Strength Tests

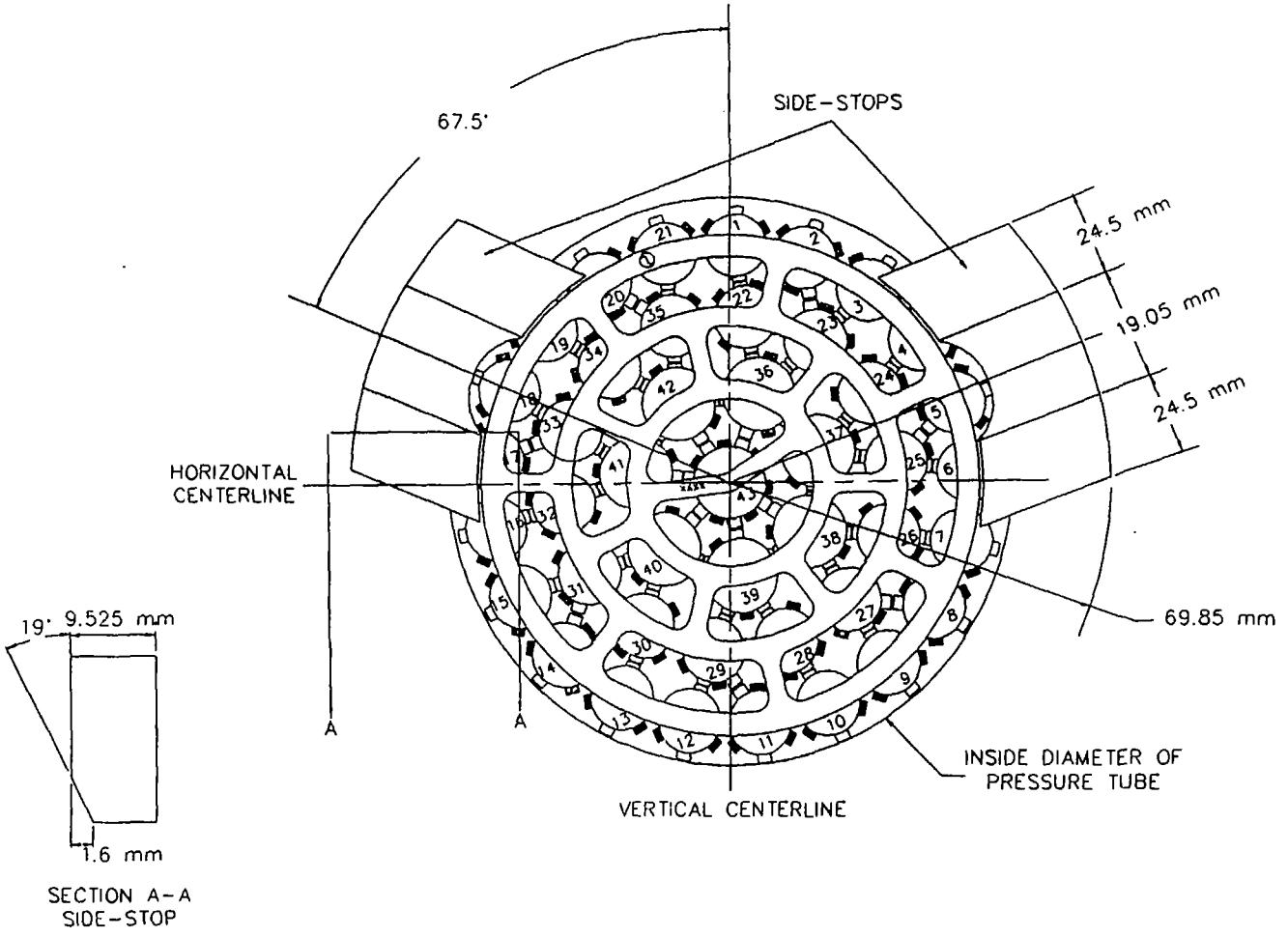


Figure 4. Assembled Fuelling Machine Side-stop for CANFLEX Fuel Strength Tests

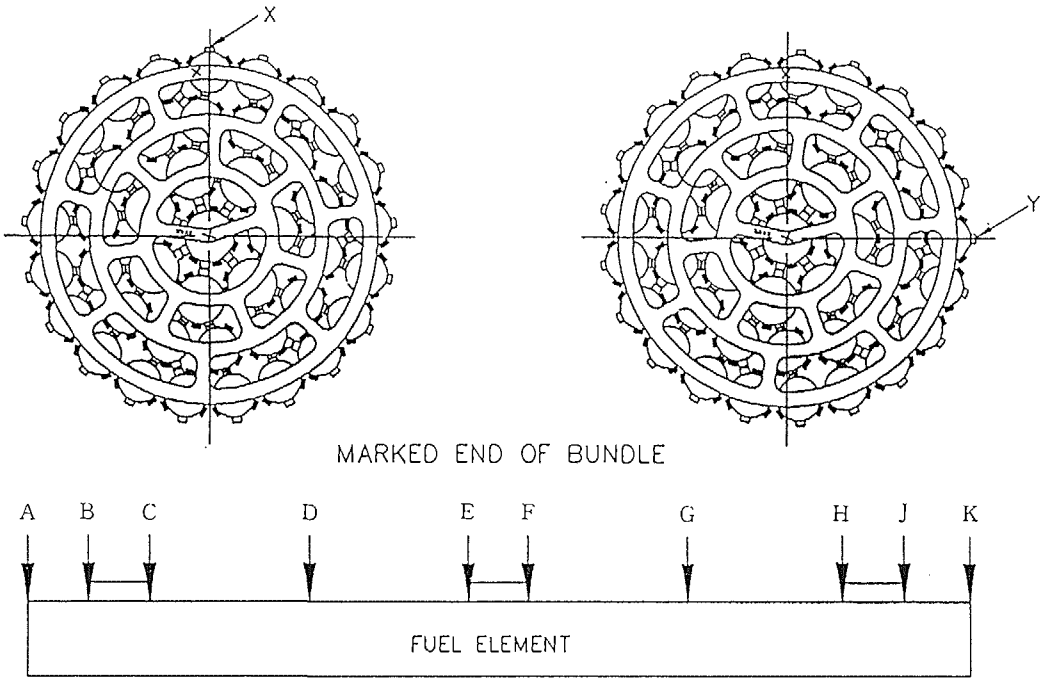


Figure 5. Element Bow Measurement Positions

서 지 정 보 양 식			
수행기관보고서번호	위탁기관보고서번호	표준보고서번호	INIS 주제코드
KAERI/TR-901/97		KAERI/TR-CX201	

제목/부제	CANFLEX Fuel Bundle Strength Tests (Test Report)
주저자 및 부서명	장석규 (중수로용 고연소도핵연료 열유동시험)
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출 판 지	대 전	발행기관	한국원자력연구소	발행년	1997. 8
페 이 지	49 p.	도 표	있음(V), 없음( )	크 기	29 x 21 Cm.
참고사항	CANFLEX 핵연료 국제 공동 연구개발 (Canada, AECL)				
비밀여부	공개(V), 대외비( ), _급비밀		보고서종류	기술보고서	
연구위탁기관			계약 번호		

초록 (15-20줄내외)

본 보고서는 중수로용개량핵연료인 CANFLEX-NU fuel의 강도시험의 실험결과에 대하여 기술하였다. 강도시험은 핵연료 재장전시 일어날 수 있는 side-stop 인접 핵연료의 변형 및 손상 여부를 검증하기 위한 시험으로 정상적인 재장전 절차시를 모사하는 double side-stop test와 비정상시를 모사하는 single side-stop test로 나누어진다. 강도시험의 규정은 이러한 두가지 경우의 재장전 작동시 side-stop에 의하여 작용되는 수력하중에 대한 인접 핵연료의 변형 및 손상이 설계 요구조건을 만족하도록 요구하고 있다. 강도시험을 위하여 side-stop simulator를 제작하였으며 보수적 수력하중(Double side-stop test: 12010N, Single side-stop: 7300N)을 가하기 위하여 압력관 유량을 조정하였다. 강도시험의 Test Rig 조건은 120℃, 11.2 MPa를 유지하면서 규정 수력하중을 내도록 유량을 조정하여 15분간 강도시험을 각각 실시하였다. 압력관내 15개 핵연료중 #13-#15는 67.5° CCW로 장전하였으며 나머지 핵연료들은 임의 각도를 갖도록 장전하였다. 시험후 side-stop 인접 핵연료의 변형도를 정밀 측정하였다. 수행된 강도시험의 절차 및 측정방법은 다음과 같다.

- 시험전 시편 측정
- Side-stop 장착 및 핵연료 다발 장전
- 시험조건 조정 및 시험 실시(2가지 경우)
- 시험후 시편 검사 및 정밀 측정

주제명키워드 (10단어내외)

강도시험, CANFLEX 핵연료, Single and Double Side-stop, Hydraulic drag force, 핵연료 다발열 압력강하, CANDU Hot Test Loop, 압력관 부수로, 핵연료 장전각 정렬

BIBLIOGRAPHIC INFORMATION SHEET

Performing Org. Report No.	Sponsoring Org. Report No.	Standard Report No.	INIS Subject Code
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Title/ Subtitle	CANFLEX Fuel Bundle Strength Tests (Test Report)
Author and Department	Chang, Seok Kyu (Fuel Themal-hydraulics Test Dept.)
Researcher and Department	C. H. Chung, B. D. Kim (Fuel Themal-hydraulics Test Dept.)

Publication Place	Taejon	Publisher	KAERI	Publication Date	1997. 8.
Page	49 p.	Fig. & Tab.	Yes(v), No ( )	Size	29 x 21 Cm.
Note	International Joint R&D for CANFLEX Fuel Bundle (Canada, AECL)				
Classified	Open(√), Restricted( ), ___ Class Document		Report Type	Technical Report	
Sponsoring Org.			Contract No.		

Abstract (15-20 Lines)

This document outlines the test results for the strength tests of the CANFLEX fuel bundle. Strength tests are performed to determine and verify the amount of the bundle shape distortion which is against the side-stops when the bundles are refuelling. There are two cases of the strength test; one is the double side-stop test which simulates the normal bundle refuelling and the other is the single side-stop test which simulates the abnormal refuelling. The strength test specification requires that the fuel bundle against the side-stop(s) satisfies its required design conditions after the test under the conservative hydraulic force conditions(Double side-stop test: 12010N, Single side-stop: 7300N) in two cases. The side-stop simulators for this test were fabricated and the flow rates were controlled to provide the required conservative hydraulic forces. The test rig conditions of 120℃, 11.2MPa were retained for 15 minutes after the flow rate was controlled during the test in two cases, respectively. The bundle loading angles of #13-#15 among the 15 bundles were 67.5° CCW and others were loaded randomly. After the tests, the bundle shapes against the side-stops were measured and inspected carefully. The important test procedures and measurements were discussed as follows.

- Test bundle measurements before the test
- Side-stop simulator installation and bundle loading
- Control the flow rate with specified test conditions and perform the test (2 cases)
- Inspections and measurements of the fuel bundles after the tests

Subject Keywords (About 10 words)

strength test, CANFLEX fuel bundle, Single and Double Side-stop, Hydraulic drag force, Pressure drop of fuel bundle string, CANDU Hot Test Loop, Pressure tube subchannel, Fuel bundle alignment