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Dry and Wet Testing of an Automated Fish Sorting System Which Uses Machine Vision

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DRY AND WET TESTING OF AN AUTOMATED FISH SORTING SYSTEM WHICH USES MACHINE VISION

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ABSTRACT

McCarthy, Kevin, 1988. Dry and Wet Testing of an Automated Fish Sorting System Which Uses Machine Vision. Can. Ind. Rep. Fish. Aquat. Sci. ____

A prototype Fish Monitoring System (FMS-1000) was developed during 1984-88. The final production prototype was fabricated by a company in Ontario, Canada, that specializes in the building of custom conveyor systems. The system included conveyor belts, a light table and a system of pneumatically controlled chutes and gates in order to route different species/sizes of fish to different destinations. Upon completion of the unit, a team from Grove Telecommunications Ltd. travelled to the fabricator's plant to perform dry testing to ensure the design specifications had been met before shipping the unit to St. John's, Newfoundland. The system was then installed at Grove's development facility in St. John's where a series of wet tests were conducted to determine the accuracy and durability of the system. Minor mechanical difficulties were noted and modifications were made to correct them.

PREFACE

Grove Telecommunications Ltd. has developed a machine vision - based fish sorting system which can sort fish by species, length and weight - the FMS 1000. After actual production testing of two prototype units, Grove had the third and final production prototype fabricated in Ontario, Canada, by a company specializing in the design and fabrication of custom conveyor systems. A contract was awarded to Grove Telecommunications to perform both dry and wet tests of this final production model. These tests were carried out in order to prove the reliability, durability and accuracy of the FMS 1000.

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INTRODUCTION

The purpose of this project is to finalize development of a commercial prototype of the FMS 1000 Fish Monitoring System.

Grove Telecommunications is engaged in the development of a vision-based fish identification, sizing and sorting machine which introduces new innovative technology strategies to the world fish industry. The sophisticated computer vision-based machine sorts fish by species, length and weight, thereby eliminating hand labour and optimizing the yields of fish filleting lines.

RESULTS AND DISCUSSION

BACKGROUND

Approximately four years ago, Grove Telecommunications commenced development of a fish sorting machine that would allow sorting of fish by species, length and equivalent weight, resulting in increased filleting yields and reduced manpower. The sorting information from a machine on a vessel (or ship) at sea could also be transmitted to shore to form a useful management data base.

The first prototype, the FMS 1000, was a stand-alone vision system capable of directing the fish to one of six possible destinations. Basically, the system consisted of a translucent, high-speed conveyor belt with underlit fluorescent lighting. A video camera, mounted over the belt, took an outline of the fish passing underneath which was then processed by the image processor contained in the computer. Each fish was then identified and routed to the proper filleting line or containers for later processing. This function was carried out by a programmable controller designed to enable pneumatic cylinders to avtivate gates and chutes for proper fish sorting.

The original prototype was 12 feet long and 40 inches wide, exclusing the chute system. The belt was a translucent Volta FMW-400 UHMW , 36" wide, which allowed light from the light table to shine through. Light was provided by 12 fluorescent tubes, each 48 inches long. A belt gear motor was selected to drive the main vision belt at 230 feet per minute, or 46" per second.

A second prototype was built to overcome some of the problems encountered with the FMS 1000. In this follow-up design, belt speeds were increased to achieve greater throughput. Also, the chutes were replaced with pivoting conveyor belts, which provided faster fish handling and dry belt surfaces, as well as a lower machine profile. The gate action was also changed. Instead of the gate pushing a fish into a side chute, the gate now diverted the fish onto the appropriate pivotign conveyor. The system could now sort the fish to eight different destinations instead of the six available on the original prototype.

After a period of testing and observation, some deficiencies were observed, such as:

(a) high vibration levels throughout the machine, resulting in poor computer vision and shortened life of some key components;

(b) poor sanitary design and ease of maintenance;

(c) poor reliability;

(d) failure to meet occupational health and safety regulations;

(e) borderline capability to meet rated fish handling capacity.

At the same time, it was concluded that the basic machine concept and vision system performed well enough and didn't require further modifications.

In order to overcome the basic deficiencies outlined above, the following recommendations were made for the final production prototype design:

1. Modularize the fish vision sorting machaine into a separate vision machine and a sorting machine to isolate the vibration and provide sorting flexibility.

2. Use lighter structural framing and belting on the pivoting conveyors to reduce shock and vibration.

3. Use fully cushioned air cylinders to further reduce shock.

4. Use heavy tempered glass on the top of the light box in place of plexiglass to prevent discolouration and scratching of the surface.

5. Use sanitary lightweight belting and small crowned stainless pulleys to reduce weight and price of the machine, to increase durability and sanitation, and to provide better belt tracking.

6. Use smaller gearmotors to reduce weight and cost.

7. With smaller pulleys and new belting, the drive motor should be located on the exit end of the vision conveyor in line with good conveyor design.

8. Expose a small section of the vision belt underside for easy inspection and continuous spray cleaning.

9. Incorporate into the design a control panel with motor starters, transformer and an emergency stop button.

10. Use chrome plated bearing mounts, rather than painted ones.

11. Install plexiglass safety shielding in the take-off conveyor area.

12. Use quick exhaust valves with silencers for faster cylinder action and quieter operation.

13. Check with Agriculture Canada regarding fish plant equipment approvals. Check United States FDA and USDA equipment approval regulations to ensure compliance. Also, check occupational health and safety regulations.

CONSTRUCTION OF PRODUCTION PROTOTYPE MACHINE

The previous prototype machines were constructed by a local fabricating company in St. John's. Nfld. These prototypes demonstrated the vision sorting principles very well. For the final production prototype, it was decided to use the services of a development conveyor fabricator familiar with high speed food industry conveying systems. Several Ontario companies were contacted.

The company that appeared to have the most expertise in the area was Custtech International Inc., 81 Brisbane Road, North York, Ontario. Its specialty was designing and developing custom specialty conveyors, primarily for the food industry.

SAFETY AND SANITATION ASPECTS

In previous prototype machines, some safety and sanitary aspects were overlooked. With the final prototype, Grove Telecommunications researched all regulations concerning safety and sanitation to ensure the system could meet or exceed regulatory approval. In Appendix A, a general report on electrical, occupational health and safety, and food sanitary regulations for Canada, the United States and other countries is given.

The government body for electrical regulations in Canada is the Canadian Standards Association (CSA). In order to minimize testing, all electrical components selected for the control panel have CSA and Underwriters'

Laboratory (UL) approvals. In order to simplify electrical approvals and costs of same, the fish sorting system should be field approved by a provincial electrical inspector where the system is installed. Local hydro inspection approval is sufficient without CSA approval. However, each new system in Canada will require field approval.

For the United States market, local state approval should be used initially. If sufficient market penetration occurs, UL approval should be obtained from Underwriters' Laboratories Incorporated. Procedure for this approval is outlined in Appendix A. All electrical components in the control panel have UL approval.

For the international market, the machine electrics should meet International Electro-Technical Commission (IES) and International Organization for Standardization (ISO) standards. In Europe, approvals are not legally mandatory. The best procedure is to contact the country in question to see which electrical regulations should be met. In most cases, the machine purchaser should be able to assist with this information.

In Canada, operator safety of a machine is regulated by the provincial Occupational Health and Safety Division of the Department of Labour. OHSA has no specific safety standards for a fish vision sorting machine. Some regulations, such as machine guarding, are specifically outlined under the Regulations. The best course of action would be to get the provincial OHSA inspector to evaluate the machine for worker health and safety hazards.

In the United States, the federal government enacts the Occupational Safety and Health Act. As well, each state has its own safety standards. The OSHA Act, as set up, puts the responsibility for machine safety directly on the end user, not the manufacturer of the machine. In the case of the fish sorting machine, it is desirable at the time of installation that Grove request an OSHA compliance officer to inspect the machine.

In the international market, safety regulations are the responsibility of the manufacturer. It is desirable to contact the proper authorities in the respective country of sale for more details.

Food processing machinery sanitation is regulated in Canada by Health and Welfare Canada, as well as Agriculture Canada. All components in contact with the food product must be approved.

In the United States, the belting selected for the machines meets Food and Drug Administration (FDA) codes so further approvals at the federal level should not be required. At the time of installation, it may be desirable to check state and local jurisdictions for other sanitary approvals required.

In the international market, it is desirable to contact the proper authorities for sanitary standards. Many countries do accept the USFDA approvals.

DESIGN OF THE CONTROL PANEL

A major area of concern was the safety of the system. In the system are high speed conveyor belts, as well as several high velocity air cylinders. To meet safety requirements, a central control panel would be required with kill switch and electrical disconnect. The panel would also be used to house the motor starters and transformer power supply for the light bank.

The starters and transformer selected were sized to handle the following:

(a) one 3 HP sorting conveyor drive motor 575 volts/3 phase/60 Hz;

(b) one 1/2 HP vision conveyor drive motor 575 volts/3 phase/60 Hz;

(c) one light bank consisting of 16 fluouescent bulbs at 40 watts each.

The control panel selected was a 16" wide by 20" high by 8" deep, 304 stainless steel Nema 4X corrosion resistant, water-tight panel with electrical disconnect. Illuminated push-pull switches on the panel face were used to start-stop the vision conveyor, sorting conveyor and light bank.

The control panel was mounted on the infeed conveyor frame. Solid PVC conduit was used to interconnect the panel to the motors and light bank. In order to allow disassembly of the electrical lines for shipping the modules, short, sealtite cables were used between the modules.

At the time of testing the panel, it was discovered that the light bank actually consisted of 18 fluorescent bulbs of 60 watts each. As a result, the existing panel transformer was borderline sized. Also, the two amp fuses were replaced with larger three amp fuses.

Future control panels should be designed with the following changes:

(a) larger control panel;

(b) larger transformer to handle the bigger light bank loading;

(c) use of 3 amp fuses instead of 2 amps;

(d) separate start/stop pushbuttons of momentary contact design (in the event of power failure, the start push button must be pressed to re-start the conveyor);

(e) use of Cutler-Hammer jumbo nameplates so all the conveyor description can be included with the start designation;

(f) addition of an hour time meter on the front of the panel (to provide a guide for maintenance programs);

(g) addition of company logo and name of system.
The control panel design in Appendix B includes all the design changes outlined above.

Another consideration to safety might be an extra emergency stop button on the opposite side of the machine from the control panel. The local safety inspector should be contacted to determine the necessity of this additional safety feature.

DRY TESTING OF THE PRODUCTION PROTOTYPE

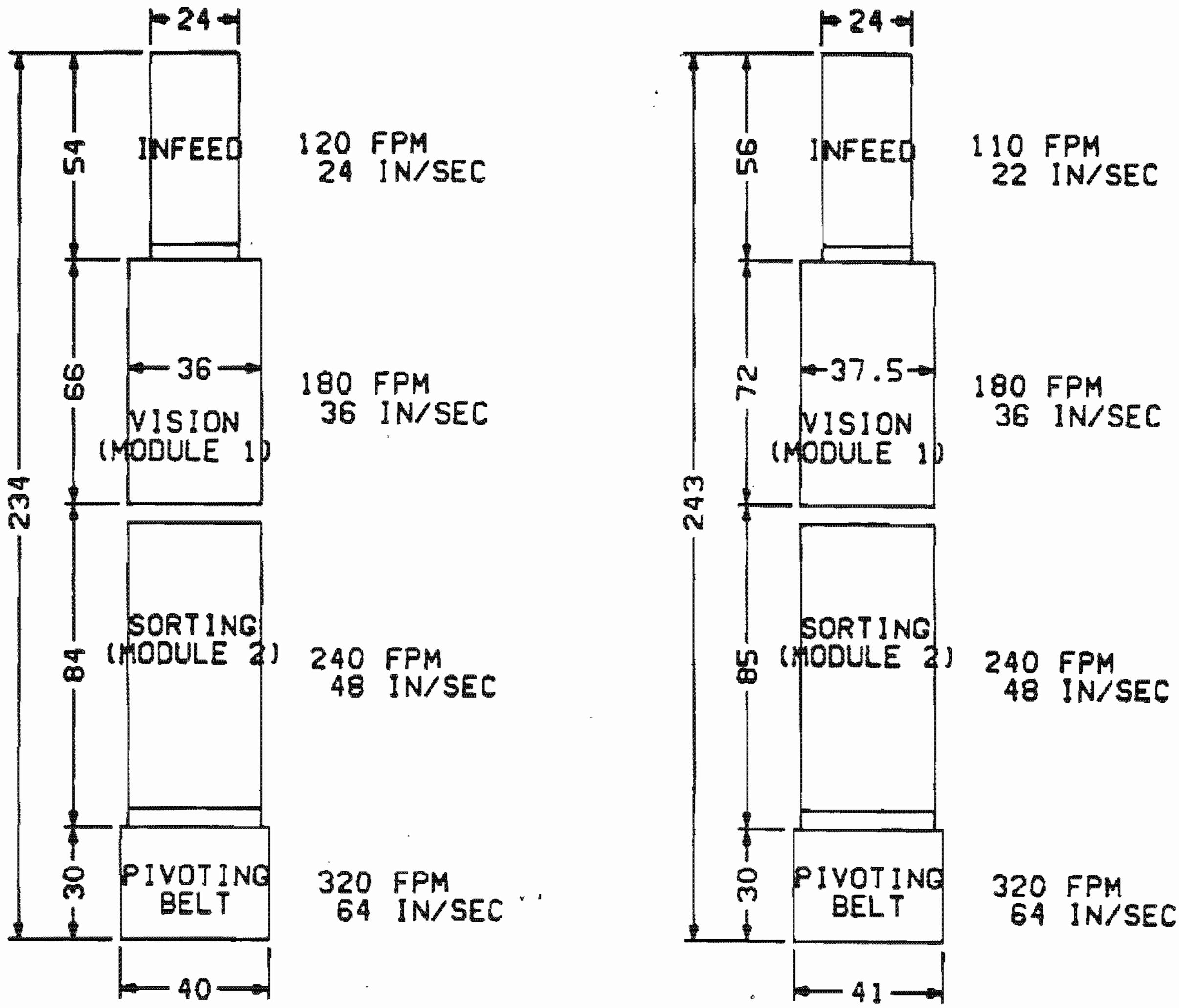
Before dry testing, the machine was examined for structural design, quality of workmanship, and dimensions of modules, belts and rollers. Structural design and rigidity were considered excellent, as was quality of workmanship. Dimensions of modules and belts are shown on the following page, along with the earlier proposed design. Belt widths on the vision sorting and pivoting conveyors were slightly wider in order to agree with standard metric widths. Also, the lengths of the modules were slightly wider in order to agree with standard metric widths. Also the lengths of the modules were slightly longer than the proposed design, but still considered within allowable limits. Also, the lengths of the modules were slightly longer than the proposed design, but still considered within allowable limits.

Pulley dimensions on the vision module were 4 1/4" diameter instead of 2 1/2" diameter. The larger diameter was required to prevent belt slippage.

The vision illumination box included 18 60 watt fluorescent bulbs instead of 16 40 watt bulbs as originally specified. This increase in intensity was essential to give better vision definition, particularly on the edge of the vision belt. The glass top selected was a tempered, clear type for durability and scratch resistance. All other details on the vision module were as specified.

The infeed conveyor attached to the vision module was built as specified, except for one variation. Black index markings were placed at 22 inch centres instead of 24 inch centres because of the 100 inch overall belt length. This allowed for exactly five index positions on the infeed

FISH MONITORING AND SORTING CONVEYOR SYSTEM



PROPOSED DESIGN

FINAL DESIGN

NOTE:
WIDTH DIMENSIONS ARE BELT WIDTHS IN INCHES.
LENGTH DIMENSIONS ARE MACHINE LENGTHS IN INCHES.

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belt. Because of the shorter index spaces, the infeed belt speed was reduced to 110 feet per minute from the specified 120 feet per minute. Overall, fish handling capacity remained at 120 fish per minute for double lane feed. Should 22 inch index spacing be too close (i.e. get fish overlapping), then four index marks per 110 inch belt at 27.5 inch spacings is an alternative design. However, at this spacing, infeed belt speed would have to be increased to 137.5 feet per minute to keep the fish throughput at 120 fish per minute.

Drive horsepower for the vision conveyor and infeed unit was 1/2 HP instead of 1 HP, as specified. The smaller motor was quite acceptable, as belt loadings were not has heavy as originally estimated. Motor voltage was 575/3/60, rather than the specified 120/1/60, as three phase power would be required for the other conveyor motor. Sprocket sets interconnecting the vision conveyor and the infeed conveyor had 14 teeth on each sprocket. As well a 14/15 sprocket tooth combination was also available to allow speed variations between the two belts of +6.7 percent.

All formed and sheet parts were 304 stainless steel with #4 finish, as specified. All structural framing and camera mount assemblies were of 304 stainless steel with pickled finished, except the welds which were brush finished to clean up the rough edges. The specifications had asked for brushed finish on all structural framing, but it was concluded that this would add nothing to the machine. For those customers that prefer such a finish, this should be treated as an option.

Sorting conveyor pulleys were 4 1/4" diameter rather than the 2 1/2" diameter specified, again for better drive.

On the four pivoting conveyors, the drive pulley was 4 1/4" diameter, instead of the 2 3/8" diameter, while the tail pulley was 2 1/4" diameter, instead of the specified 2 3/8" diameter. Head pulley diameters were increased to allow space for the unique bearing arrangement on the drive shaft of the pivoting conveyors. In order to group the pivoting conveyors close together, the bearings on the pivoting conveyor side skirts did not fit on the drive shaft. Rather, these bearings were mounted internally on the inside of the drive pulleys. The drive pulleys, in turn, were keyed to the drive shaft.

A 1/4" thick Lexan safety shield was used instead of a 3/8" thick plexiglass shield specified. It was felt the added strength of Lexan was worthwhile in spite of the higher costs involved.

Martonair Model 8050 tandem air cylinders were used to raise and lower the pivoting conveyors.

The drive motor selected for the sorting conveyors was a 3 HP variable speed unit, instead of the 1 HP unit specified. A larger motor was used because of the high speeds (i.e. - 200 to 300 feet per minute) required for testing the sorting conveyor prototype. Nominal belt speed was 240 feet per minute.

The actual dry run testing of the machine showed the unit easily met the performance guarantees. The only areas of of concern was the pivoting conveyor drive shaft. Drive shaft deflections of 0.050 inches to 0.055 inches were detected in the top pivoting position. Deflection was due to the fact that in this position, the pivoting air cylinder was not at right angles to the conveyor, thereby putting side forces on the conveyor and shaft. Cushioning built into the air cylinders did not appear to help.

A stress analysis of the shaft for various deflections and loadings was performed. The results are shown in the following section. Even at deflection of 0.1 inches, the lifespan of the 1 1/2" diameter drive shaft was not reduced. The only slight concern with shaft deflection was the wear effect back on the pivoting conveyor bearing and framework.

Another minor concern was the relatively high temperature inside the vision table. Typical temperatures on dry runs were about 160 F. What effect fish on the vision belt would have on temperature was not known.

Bearing temperatures were generally very low, indicating proper sizing of these components to ensure very long life.

SHAFT DEFLECTION STUDY

This study was done to determine the life cycle of the fish monitoring system take-off shaft. The shaft is 1.5" in diameter and 42.5" long. The existing condition has the shaft operating at 500 RPM. There is an unknown load at the centre and bearing supports at both ends. The observed deflection at the middle of the shaft is about 1/16".

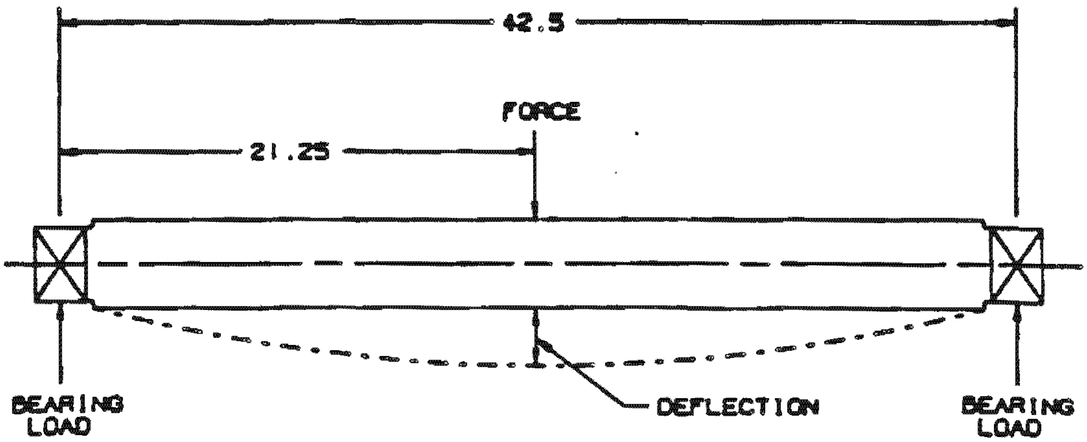
A computer program was utilized to estimate the magnitude of the centre load, based on the deflection of the shaft. The following summarizes results of the calculations.

DEFLECTION (INCH)	FORCE (LBS)	STRESS (PSI)
0.100	455	14,945
0.075	339	11,213
0.050	223	7,477

The calculations used three different deflection values to increase the accuracy of the observation. The stress values are the maximum stress on the shaft.

The next step was to determine the life of the shaft. An S-N diagram was used. The diagram (next page) predicts the fatigue life of the shaft based on its stress load. The diagram indicates the life cycles would be infinite if the stress load is less than 50% of the ultimate tensile strength of a 304 stainless steel shaft is 85,000 PSI and the infinite life cycle level is at 42,500 PSI.

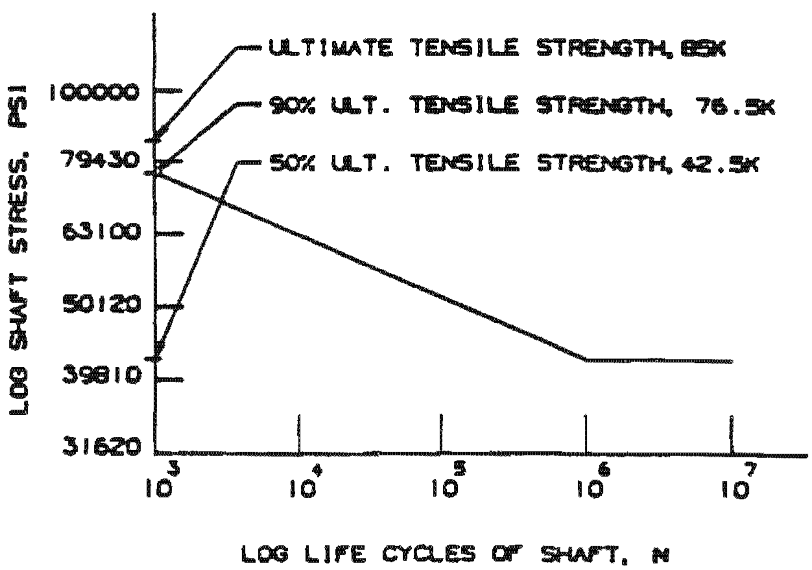
Considering the worst condition with 0.100" deflection on the shaft, the stress load is only 14,945 PSI, which is less than 42,500 PSI. Therefore, the shaft has an infinite life under the present loading conditions.



SHAFT DIAMETER: 1.5 INCHES

FORCE (LBS)	DEFLECTION (INCH)	STRESS (PSI)
455	0.100	14945
339	0.075	11213
223	0.050	7477

S-N DIAGRAM OF STAINLESS STEEL SHAFT



NOTE: ANY SHAFT WITH STRESS LESS THAN 50% OF THE ULTIMATE TENSILE STRENGTH HAS AN INFINITE LIFE.

WET TESTING OF THE PRODUCTION PROTOTYPE

The wet testing of the FMS-1000 included several tests to determine the accuracy of the system. It was discovered during these tests that the thickness of the tail of a fish had an effect on the accuracy of the length calculation. If the tail was thin, more light would shine through it causing the length reading to be low. This problem was alleviated by adjusting the aperture of the lens as well as the input threshold value. The software was also modified to make a different length adjustment for each species.

Tests were then carried out whereby actual lengths (measured by Grove personnel) were compared to FMS lengths. These tests showed accuracy rates of 99.3% for cod, 99.2% for flatfish and 98.0% for redfish. Two points should be noted:

1. The 'actual' measurement made by Grove personnel can only be considered accurate to within 1/4", therefore some of the error can be attributed to the actual measurements.

2. Although the observed errors in redfish are consistent with the observed errors in the other species, the percentage error (observed error/actual length) appears higher due to the fact that the average length of the redfish used is much less than the average length of the other species.

   Calculations of the above results are presented in Tables 1, 2, and 3.

Repeatability tests were also conducted during which five individual fish were measured by the FMS a total of 10 times each. The mean and variance of each set of measurements were calculated along with the average error or deviation from the mean. Results show a precision rate of 99.87% with an average variance of .0020. Calculations of these results are presented in Table 4.

Tests performed to determine the accuracy of the weight calculation showed that the weight of fish in a particular size range varies depending on the time of year and area where it was caught. There seems to be other factors involved here, including the method with which fish was stored on the boat. In order to accommodate this variation, Grove has included a weight calibration option with the FMS. The weight calibration is performed by the operator through the operator's control panel. The weight of a sample of fish calculated by FMS is entered along with the actual weight of this sample. The software then adjusts its weight formulas accordingly.

The accuracy of the species recognition software was computed to be approximately 95%. The most common errors encountered were small flatfish being classified as redfish and small catfish being classified as cod. Further software development is presently being performed to try to eliminate these concerns.

MECHANICAL DIFFICULTIES/SOLUTIONS

During the wet testing of the Fish Monitoring System, Grove personnel noted several mechanical difficulties, such as the accumulation of food materials on the conveyors, unreliability of belt tracking, heat build-up in the light box, premature wear of the sorting discharge conveyors and the roughness of the sort conveyor belt.

The following is a list of solutions to eliminate these mechanical difficulties:

ACCUMULATION OF FOOD MATERIALS ON INFEED AND DISCHARGE SORTING CONVEYORS

Over the entire period of wet testing, the infeed and discharge sorting belts were found to be very hard to clean; therefore, the belts were slowly becoming discolored due to accumulation of food materials. To reduce this problem, additional high pressure spray manifolds have been ordered and will be received shortly. This is expected, in conjunction wih a regular cleaning procedure, to alleviate this problem.

BELT TRACKING/VISION CONVEYOR

The 'vision conveyor' belt tracking was found to be unreliable in that it could track well for days and then with no warning go off track completely either to one side or the other. Upon investigation, it was found that all the rollers and idler/snub pulleys were crowned or crowned much too greatly by approximately six times the Leder belt manufacturer's recommendations. Subsequent to these findings, the crowning of the idler/snub pulleys was machined completely away and the head/tail rollers crown was reduced to meet Leder's recommendations. Belt tracking reliability has since improved dramatically.

LIGHTING/VISION CONVEYOR

Due to heat build up inside the light box, actual light intensity decreased over a period of time, thereby reducing the sensitivity and accuracy of the vision system. At first, a cooling fan (intaking and discharging air to atmospher) was tried and this solved the problem. However, there was concern over water being forced through the intake/discharge vents during daily washdown. A closed system was then tried, with a water type heat exchanger using internal, recirculating forced air. The fixtures were raised 1 1/2" to allow the cooled air to circulate beneath them thus cooling the ballasts in the fixtures as well as the tubes. This significantly reduced heat build up with the addition of having no possible water intrusion due to daily washdowns.

SORTING DISCHARGE CONVEYOR

The pivot pins for the pneumatic cylinder on the sorting discharge conveyors were found to have severe premature wear, first noticed as ametallic clicking as the conveyors travelled from one position to another. Upon investigation, it was found that the pins supplied were not pins but 3/8" diameter standard stainless steel bolts and that major wear, after only 20 - 30 hours of operation, was occurring on these bolts. To solve the problem, the clevis holes were enlarged to .500" and .500" hardened steel pins were used as replacements for the bolts. This seems to have solved the problem. However, as a further improvement, hardened steel pins with grease fittings are on order and this should completely eliminate, with regular greasing, any problems in this area.

SORT CONVEYOR BELT

The original sort belt was found to be too rough in that fish would not easily slide from one lane to another. A smooth surfaced belt was then installed which solved the problem.

CONCLUSIONS

The production prototype of the fish vision monitoring and sorting conveyor system performed very well, meeting or exceeding all specifications. The only areas of minor concern are as follows:

(a) long-term durability of pivoting conveyors, if air cylinder shocking increases from present levels;

(b) present location of floor mounts for pivoting conveyor air cylinders are not at the optimum location for minimal shocking;

(c) long-term durability of clevises and pins on pivoting conveyor on air cylinders due to problem above;

(d) hand-sewn air cylinders bellows may not be durable enough;

(e) lack of access holes to hand-spray clean sorting and infeed conveyors;

(f) non-food approved silicon cement on infeed conveyor belt guide marks.

Other areas of cosmetic and visibility concern are:

(a) camera mount appears too massive, heavey and of pickled finish;

(b) outside rails on sorting conveyor are too high, not transparent and not easily adjustable.

With the completion of the wet tests, Grove feels that it now has a system that is superior to the previous models. All mechanical difficulties with the previous models have been overcome and many design changes and improvements have been made. The separation of the three modules and the improved camera mount have eliminated any vibration in the camera which resulted in less variation in the image and the length calibration.

With all these improvements, the successful completion of the dry/wet tests and endurance test, Grove is confident that the FMS 1000 Fish Monitoring System is now ready for the marketplace.

RECOMMENDATIONS

1. The air cylinder shocking to be minimized by fine tuning the adjustable cushions on each cylinder.

2. Locktite Threadlocker adhesive to be used on all threaded fasteners on the pivoting conveyors.

3. The air cylinder floor mounts to be moved approximately 16 inches further away from the sorting conveyor frame than the dry testing position used. Also, the sorting conveyor should be raised 5/8".

4. The air cylinder clevises for the pivoting conveyors to be of the bearing configuration type to reduce side loading and wear.

5. The hand-sewn air cylinder bellows should be replaced with one-piece moulded bellows.

6. Cleaning access holes should be added to both the sorting conveyor and infeed conveyor side frames.

7. Dow Corning #732 or #734 FDA approved silicon cement to be used for making the infeed conveyor belt guide marks.

8. The camera mount could be constructed of 2" diameter, 0.65" wall, polished stainless tubing to reduce the weight and improve the cosmetic appearance of this component.

9. The outside rails of the sorting conveyor could be of an off-the-shelf, adjustable design, as shown in Appendix D. Attached to the UHMW insert could be a clear, plexiglass sheet rail, perhaps 6" high.

10. The revised control panel design in Appendix B should be used for future machines.

11. A number of grease nipples for bearings were hard to access and to be replaced by 'L' type nipples.

12. Spacer/Alignment bolts to be installed to ensure proper machine set up.

13. Slotted holes in the adjustable leg based plates to be machined to ease machine alignment.

14. Additional grease points are being considered at the pivoting discharge conveyor drive. At present sealed bearings are being used.

15. At the divert arms, stronger bearings are being considered to replace the UHMW-PE sleeve type bearings.

16. The sort conveyor drive/tail rollers are scheduled to have crowns machined down (per Leder's specification) to eliminate 'hump' in sort belt.

17. Name plates are presently on order and will be placed on each conveyor unit when received.

TABLES

TABLE 1. RESULTS OF LENGTH ACCURACY TESTS OF COD

ACTUAL LENGTH	FMS LENGTH	ERROR	% ERROR
23.75	23.7	0.05	0.2
23.75	24.0	0.25	1.0
24.0	23.7	0.30	1.2
24.0	24.1	0.10	0.4
23.5	23.5	0.00	0.0
24.0	24.5	0.50	2.1
23.0	23.0	0.00	0.0
24.25	24.1	0.15	0.6
23.0	23.3	0.30	1.3
25.0	25.1	0.10	0.4
23.75	23.7	0.05	0.2
23.5	23.3	0.20	0.8
24.75	24.6	0.15	0.6
25.5	25.3	0.20	0.8
24.0	24.0	0.00	0.0
27.0	27.5	0.50	1.8
25.25	24.9	0.35	1.4
29.5	30.0	0.50	1.7
25.75	25.5	0.25	1.0
19.0	19.1	0.10	0.5
22.5	22.4	0.10	0.4
21.0	20.8	0.20	0.9
23.25	23.4	0.15	0.6
23.25	23.4	0.15	0.6
24.25	24.3	0.05	0.2
23.75	23.9	0.15	0.6
24.0	24.1	0.10	0.4
19.0	18.9	0.10	0.5
20.5	20.5	0.00	0.0
24.5	24.7	0.20	0.8

Average Error 0.176 inch
Average % Error 0.700 %

NOTE:

Actual length measurement can only be considered accurate to the nearest 0.25 inch.

Error calculated as follows:

Error - Absolute value of actual length minus FMS length

% Error - Error divided by actual length

TABLE 2. RESULTS OF LENGTH ACCURACY TESTS OF FLATFISH

ACTUAL LENGTH	FMS LENGTH	ERROR	% ERROR
20.25	20.50	0.25	1.2
27.05	16.85	0.15	0.9
15.25	15.25	0.00	0.0
18.0	18.05	0.05	0.3
16.75	16.65	0.10	0.6
18.5	19.15	0.65	3.5
18.75	18.85	0.10	0.5
16.25	16.25	0.00	0.0
23.0	22.95	0.05	0.2
19.25	19.25	0.00	0.0
18.25	18.15	0.10	0.5
19.25	19.45	0.20	1.0
16.75	16.55	0.20	1.2
17.5	16.85	0.65	3.7
15.5	15.55	0.05	0.3
18.0	17.95	0.05	0.3
20.05	19.85	0.15	0.7
20.25	20.25	0.00	0.0
20.05	20.00	0.00	0.0
17.25	17.30	0.05	0.3
17.25	17.50	0.25	1.4
18.0	18.20	0.20	1.1
19.25	19.00	0.25	1.3
21.0	21.00	0.00	0.0

Average Error 0.15 inch
Average % Error 0.794 %

NOTE:

Actual length measurement can only be considered accurate to the nearest 0.25 inch.

Error calculated as follows:

Error - Absolute value of actual length minus FMS length

% Error - Error divided by actual length

TABLE 3. RESULTS OF LENGTH ACCURACY TESTS OF REDFISH

ACTUAL LENGTH	FMS LENGTH	ERROR	% ERROR
11.5	11.5	0.00	0.0
12.0	11.7	0.30	2.5
13.0	13.2	0.20	1.5
11.25	11.1	0.15	1.3
10.5	10.5	0.00	0.0
12.5	12.4	0.10	1.0
11.5	11.7	0.20	1.7
11.0	10.8	0.20	1.8
11.75	12.6	0.15	1.3
11.25	11.3	0.05	0.4
11.75	11.1	0.65	5.5
11.25	11.4	0.15	1.3
10.25	10.0	0.25	2.4
10.25	10.6	0.35	3.4
11.0	11.1	0.10	0.9
12.5	12.1	0.40	3.2
12.25	12.6	0.35	2.9
13.0	12.3	0.30	2.3
10.25	10.7	0.45	4.4
11.75	11.5	0.25	2.1
11.5	11.4	0.10	0.9
11.75	12.0	0.25	2.1
13.5	13.0	0.50	3.7
14.0	14.2	0.20	1.4
12.75	12.5	0.25	2.0
21.0	21.3	0.30	1.4
13.75	13.7	0.05	0.4
15.0	15.0	0.00	0.0
13.75	13.8	0.05	0.4
13.0	12.0	1.00	7.7

Average Error 0.24 inch
Average % Error 1.99 %

NOTE:

Actual length measurement can only be considered accurate to the nearest 0.25 inch.

Error calculated as follows:

Error - Absolute value of actual length minus FMS length

% Error - Error divided by actual length

TABLE 4. RESULTS OF REPEATABILITY TESTS

Fish #	Mean (inches)	Variance	Average Error (deviation from mean)	%Error
1	15.61	.00322	.036	.228
2	19.38	.00178	.032	.162
3	24.81	.00100	.018	.072
4	28.02	.00178	.032	.114
5	32.20	.00222	.020	.062
Average:		.00200	.0276	.1276