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THE FERIC DIFFERENTIAL-INTERLOCK YARDING CRANE CONCEPT

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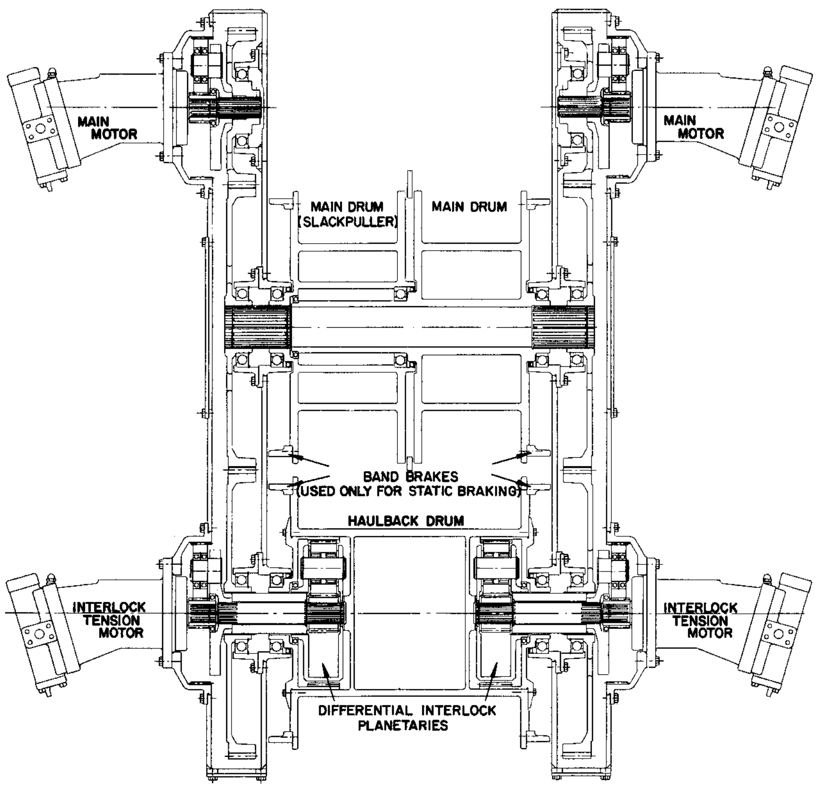
May 1987



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PREFACE

The FERIC differential-interlock yarding crane could reduce present coastal yarding crane operating costs by 11 percent. The concept has evolved from the similar S.Y. 235 yarding crane developed by Finning Tractor and Equipment Co. Ltd. and Lantec Industries Ltd. for Interior applications. The improved theoretical performance of the FERIC yarding crane results from the differential interlock's more efficient utilization of available horsepower.

In developing this concept, FERIC has spent considerable time in consultation with the logging industry assessing current practices and requirements. Performance criteria were optimized through extensive computerized evaluations.

The author thanks the following individuals and organizations for their help in developing this concept:

Finning Tractor and Equipment Co. Ltd.
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Whonnock Industries Ltd.
B.C. Forest Products Ltd.
Northwood Pulp and Timber Ltd.
Weldwood of Canada Ltd.
Russell and Lilly Ltd.
Mr. Hilton Lysons
Mr. Dick Herring

AUTHOR

The author is an engineering graduate from the University of Saskatchewan. From 1963 to 1973 he worked with S. Madill Ltd. designing several machines, including the original Model 044 yarding crane. Later, as a consultant, he helped in developing the Finning S.Y. 235 yarding crane. He is presently Engineering Group Supervisor with FERIC's Western Division. He has spent considerable time observing yarding crane performance on the Coast and in the Interior, and has discussed requirements with both users and manufacturers.

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SUMMARY

FERIC has developed a yarding crane concept for the B.C. coastal market which should reduce present yarding costs by an estimated 11 percent. The winch is a modular design and features an energy efficient differential interlock. It is capable of 10% more line speed from 28% less power compared to conventional interlock machines. It may be mounted along with a suitable boom and gantry on a variety of carriers.

The differential-interlock concept has been proven on the small Finning S.Y. 235 machine developed for the B.C. Interior. The FERIC proposal has 70% more mainline pull and twice the haulback line pull. The proposal should satisfy the expressed needs of owners and operators facing coastal trends towards longer yarding distances, more difficult terrain, and smaller piece sizes.

Cost savings are attributable to the use of low cost, readily available assemblies and materials, commonality of parts, and improved power efficiency. The design also places all yarding functions in a simple two-lever control arrangement which should minimize operator fatigue and training requirements.

For a forest industry striving to reduce costs, this yarding crane concept holds significant potential. It is important that the concept be developed to the prototype and production stages. To this end, FERIC is seeking and will cooperate with any prospective manufacturer interested in the commercial development of the differential-interlock yarding crane concept.

SOMMAIRE

FERIC a conçu pour le marché de la Colombie-Britannique côtière le principe d'un câble-grue mobile susceptible de permettre une réduction des coûts de téléphérage estimée à 11%. Le treuil modulaire se caractérise par un dispositif de verrouillage du différentiel à haut rendement. La vitesse d'enroulement du câble peut atteindre 10% de plus avec 28% moins de puissance, comparativement aux machines traditionnelles comportant un dispositif de verrouillage. Il peut être monté, avec un mât et une grue à portique appropriés, sur divers châssis automoteurs.

Le principe du dispositif de verrouillage du différentiel a fait ses preuves sur une petite machine, la Finning S.Y. 235, mise au point pour les conditions de la Colombie-Britannique intérieure. Le projet de FERIC prévoit une force de tirage de 70% supérieur pour le câble tracteur et du double pour le câble de retour. Ce projet devrait répondre aux besoins exprimés par les propriétaires et les opérateurs confrontés aux nouvelles conditions de l'exploitation en zone côtière: distances de téléphérage plus longues, terrains plus difficiles et pièces de bois de plus petites dimensions.

Les économies de coût sont attribuables à l'emploi de composantes et d'équipement peu coûteux, déjà disponibles, à l'utilisation de pièces communes et à un rendement amélioré. De plus toutes les fonctions de téléphérage sont commandées par un système à deux leviers dont la simplicité devrait contribuer à minimiser la fatigue de l'opérateur et les besoins de formation.

Pour une industrie forestière qui s'efforce de réduire ses coûts, le principe de ce câble-grue offre de grandes possibilités. Il est important de le développer jusqu'à l'étape du prototype, puis du modèle de production. Dans ce but, FERIC recherche un fabricant qui serait éventuellement intéressé à la mise au point et à la commercialisation du câble-grue mobile à dispositif de verrouillage et auquel l'Institut pourrait apporter sa collaboration.

INTRODUCTION

The objectives of this project were to design a more efficient yarding crane for B.C. coastal conditions using the differential-interlock principle, and to encourage and cooperate with any suitable manufacturer interested in its commercial development.

Yarding cranes were first introduced on the B.C. Coast in the mid-1960s. They were an improvement over the standard 28-m spar because of swing capability, greater mobility, increased productivity, and a smaller crew requirement. With the smaller crew and the advent of better night lighting, safe double-shifting became possible. Greater mobility permitted the wind-rowing of logs along the roadside. This reduced the need for landings and made it possible to separate the yarding and loading phases for a further increase in productivity.

One of the first yarding cranes in B.C. was the Madill 044. It featured a non-interlock winch powered by a 336-kW engine. It weighed over 100 000 kg, had a 4.37-m wide tracked undercarriage, and used a 21-m boom. The yarding crane introduced a new departure in yarding practice resulting in lower logging costs, but there were a few problems. The short boom and limited grapple control at an extended reach required closer road spacing. More attention to deflection when laying out settings was also required. In addition, the machine's weight, width, and greater mobility resulted in higher road-maintenance costs.

In the 1970s, yarding cranes with regenerative-interlock winches were introduced. Although the concept was not new, the use of it on yarding cranes was. The principle was to capture some of the energy normally lost through the haulback brake and use it to help drive the main drum. Changing spooling radii resulted in a constantly changing speed ratio between main and haulback drums. Engagement of interlock power required the use of a slipping clutch in the gearing connecting the two drums. Although the slipping clutch also dissipated energy, the efficiency was improved. The result of regenerative interlock was an increase in the haulback tension level with no loss of line speed. This improved yarding performance, particularly with poor deflection or over long distances. Some examples of regenerative-interlock yarding cranes are the Washington 88, American 7280B, Madill 122, Madill 143, and the Madill 144. Although these machines are more efficient than non-interlock machines, they are also more expensive and more complex to operate because of the slipping clutches.

In the late 1970s, Mr. Hilton Lysons, then with the U.S. Forest Service, and Lantec Industries Ltd. of Surrey, B.C., developed a small differential-interlock winch. It was hydraulically driven and was mounted on a skidder. It was to be used primarily for thinning. Based on this experience, Lysons and Lantec Industries Ltd. worked with Finning Tractor and Equipment Co. Ltd. to develop the S.Y. 235, a differential-interlock winch mounted on a Caterpillar 235 excavator. With a maximum mainline pull of 140 000 N at half drum, it was designed for the smaller wood of the B.C. Interior. The S.Y. 235 demonstrated the energy efficiency and simplicity of control possible with a differential interlock and hydraulic drive.

FERIC developed their yarding crane concept based on the original ideas of Lysons, Lantec Industries Ltd., and Finning Tractor and Equipment Co. Ltd. FERIC believed that the improved performance of the differential-interlock winch could contribute to lower yarding costs in a B.C. coastal application. As well as being larger than the Caterpillar S.Y. 235, the yarding crane developed by FERIC includes cost-saving simplifications of the gear train and winch. This report describes the new concept and the process of its development.

MARKET SURVEY AND POTENTIAL

In a market survey conducted by FERIC, forest companies, logging contractors, and yarder manufacturers were canvassed for information on both yarding cranes and spars. The consensus was that yarding cranes would continue to replace steel spars. Table 1 is a ten-year projection which shows that the number of yarding cranes operating in B.C. is estimated to almost double. Annual sales should gradually increase from the present 43 units to 53 units.

TABLE 1. Market Growth Potential for Yarding Cranes in B.C.

YEAR	WOOD PRODUCTION 1000 m^3		NUMBER OF CRANES WORKING (Note 2)	NUMBER OF CRANES TO BE REPLACED (Note 3)	NUMBER OF CRANES REQ'D FOR INCREASED PRODUCTION	TOTAL NUMBER OF CRANES SOLD
	YARDING CRANE (Notes 1 & 4)	STEEL SPAR (Notes 1 & 4)				
1986	9 115	17 885	152	22	21	43
1987	10 367	16 633	173	25	19	44
1988	11 531	15 469	192	27	18	45
1989	12 614	14 386	210	30	17	47
1990	13 621	13 379	227	32	16	48
1991	14 558	12 442	243	35	15	50
1992	15 429	11 571	257	37	13	50
1993	16 239	10 761	271	39	13	52
1994	16 992	10 008	283	40	12	52
1995	17 693	9 307	295	42	11	53

Assumptions:

1) The increased wood production for yarding cranes is estimated at 7% of the previous year's production by steel spars.
2) The average annual wood production of a yarding crane is 60 000 m^3.
3) The average life of a yarding crane is 7 years.
4) The present coastal wood production of 27 000 000 m^3 will remain unchanged over the next 10 years. Almost all of this will be harvested with cable systems.

SURVEY OF OPERATORS, MACHINES, AND OPERATING CONDITIONS

FERIC conducted field trips to Vancouver Island and the B.C. Interior to ask for operators' and owners' opinions regarding their requirements and the merits of existing machines. Observations were made on the Washington 78, 88, and 118, the Madill 044, and the Finning S.Y. 235. The following is a discussion of the findings and some of the conclusions.

1. Machines

Table 2 lists performance specifications for the more common yarding cranes used on the B.C. Coast. Except for the Madill 044, all machines feature an interlock winch. The Washington 88, the Madill 121, 122, 143, and 144, and the American 7280B are regenerative-interlock machines. The Finning S.Y. 235 and Washington 078 have differential-interlock winches. The Washington 118 is a unique machine. It featured a hydraulic motor placed in the gear train between the main and haulback drums. Both the housing and shaft rotate. Interlock is applied by pressurizing the motor inlet port through a roto coupling. Although effective, this arrangement was reported to require high maintenance.

Several factors determine machine stability. These include the machine's weight, the height of the boom, the height and arrangement of the guyline fairleads on top of the gantry, the carrier width, and the amount of counterweight. Stability, in turn, determines the line pull imposed at the boom tip. For example, the Madill 044 yarding crane is heavier, wider, more stable, and capable of a higher combined line pull than the Washington 88. However, with the greater weight, the Madill 044 is less transportable and requires a higher road standard than the narrower Washington 88.

2. Operator and Owner Comments

The survey revealed some variance of opinion on certain issues. The following is a list of features generally considered to be most desirable for a new coastal yarding crane.

a) Winch Features

- The winch should be a separate module, adaptable to a variety of existing carriers.
- Maximum usable mainline pull should be between 225 000 and 250 000 N.
- Mainline speed should reach 360 m/min.
- Maximum haulback line tension should be 135 000 N or more.
- Maximum haulback line return speed should exceed 600 m/min.
- Maximum main- and slackpuller-drum capacity should be 370 m of 22-mm diameter line. The haulback drum should hold 800 to 850 m of 22-mm diameter line. The straw drum should hold 1000 to 1200 m of 8-mm diameter line.

TABLE 2. Comparative Yarding Crane Specifications.

Make	WASHINGTON	WASHINGTON	WASHINGTON	MADILL	MADILL	MADILL	MADILL	MADILL	AMERICAN	FINNING
Model	78	88	118	044	121	122	143	144	7280 B	SY 235
Engine	Cummins V555	GM 8V71	GM 8V 92 T	GM 12V71 TV	GM 8V71 TA	GM 8V92 TA	GM 12V71 TV	GM 12V71 TV	GM 12V71	CAT 3306
Power (kW)	147	227	321	391	261	317	391	391	335	160
Converter	Twin Disc 6-F-1307-2	Twin Disc 8-FLW-1452	Clark Single Stage	Twin Disc TD 11500	Twin Disc Type 4	Twin Disc Type 4	Twin Disc Type 4	Twin Disc TD 11500	Twin Disc TD 11500	N/A
Transmission	Twin Disc TD-44-1100	Twin Disc TD-44-1131	Clark Model 8420	Two Speed	Two Speed	Two Speed	Two Speed	Two Speed	Twin Disc Hydrostatic	Variable
Fuel Capacity (L)	568	1041	1041	2460	946	946	2082	2460	2082	397
Guylines	2 Through One Fairlead	2 Through One Fairlead	2 Through One Fairlead	1	2 Through One Fairlead	2 Through One Fairlead	2 Through One Fairlead	2 Through One Fairlead	2 Through Two Fairleads	2 Through Two Fairleads
Winch	Differential Interlock	Regenerative Interlock	Hyd. Motor Interlock	Non-Interlock	Regenerative Interlock	Regenerative Interlock	Regenerative Interlock	Regenerative Interlock	Regenerative Interlock	Differential Interlock
Main Drum										
Line Size (mm)	16	19	22	25	19	22	25	25	25	19
Capacity (m)	366	533	494	536	610	457	427	427	366	396
Pull (N)[1]	225 615	277 235	271 895	270 115	176 665	193 575	408 510	408 510	358 670	140 175
Max. Speed (m/min)	411	808	573	896	833	833	813	813	671	521
Haulback Drum										
Line Size (mm)	16	19	22	16	19	22	25	25	22	19
Capacity (m)	991	1 067	1 006	1 372	1 554	975	971	971	1 250	853
Pull (N)[2]	73 425	68 085	85 440	157 975	113 920	113 920	141 065	141 065	121 485	74 760
Max. Speed (m/min)	458	963	700	905	833	833	813	813	914	521
Straw Drum										
Line Size (mm)	8	10	10	8	8	8	10	10	11	8
Capacity (m)	1 646	1 356	1 356	1 402	2 134	2 134	1 494	1 494	914	1 097
Pull (N)[3]	39 160	56 960	56 960	39 160	39 160	39 160	56 960	56 960	62 300	16 910
Max. Speed (m/min)	1 234	1 814	2 271	683	1 341	1 341	564	564	671	257
Dimensions										
Boom Height (m)	13.62	14.63	17.68	18.29	14.94	15.54	21.34	21.34	21.34	15.24
Gantry Height (m)	7.37	10.84	12.04	10.29	10.36	13.11	13.72	13.72	12.19	11.86
Width (m)	4.30	3.48	4.32	4.37	3.51	3.66	3.96	4.37	3.91	3.61
Weight (kg)	40 154	40 050	51 724	89 655	40 381	50 817	72 595	89 655	72 595	52 178

[1]Mainline pull is calculated at a half full drum.
[2]The haulback interlock tension is the maximum possible with a quarter of the line on the drum.
[3]The straw line pull is the smaller value of the maximum drum pull capability and the normal breaking strength of the line.

- It would be desirable to eliminate problems associated with open gearing by incorporating enclosed gears and splash lubrication.

- The main operating mode will be with a grapple or a drop-line carriage. The machine should also be adaptable to other modes such as highlead and gravity.

- The winch design should eliminate the use of high-cost components and materials wherever possible. Ductile iron should replace steel wherever possible.

b) Other Features

- Readily available assemblies must be used.

- The boom height should be 18 m.

- The gantry should be 10- to 15-m high. It must include a double bull's-eye fairlead arrangement for a pair of walking guylines.

- The operator's cab must be raised and protected. It must provide good visibility of the winches and setting.

- Careful consideration must be given to component access for maintenance and servicing.

- Crawler width should be approximately 3.7 m.

- Fuel capacity should cover one week of normal operation.

- The conflicting desires for portability and operating stability suggested a machine weight of 45 000 to 65 000 kg. A machine weight in excess of 65 000 kg was not justifiable.

3. Other Considerations

The survey revealed the need for clarification of the significance and comparative values of certain manufacturer specifications.

There was considerable discussion about the amount of line needed. The operator's ability to place the grapple on a log diminishes rapidly once the carriage is more than 180 m from the machine. Nevertheless, manufacturers have provided mainline capacities in excess of 360 m and as high as 600 m. The use of spotters, video equipment, and remote control will improve the operator's ability for long reaches. However, it may be unreasonable to consider reaching beyond a certain limit on the Coast because of rough terrain and reduced deflection. The consensus was that 360 m of line capacity is reasonable.

The mistaken idea that the most productive machine is the one with the greatest pull has encouraged manufacturers to quote bare-drum pull at converter stall. This is a meaningless figure. Bare-drum pull cannot be maintained as the spooling radius increases. Also, no work is done when the converter stalls and operates at 0% efficiency.

A three-stage torque converter is designed for continuous operation at no less than 70% efficiency. Anything less than 70% will cause overheating. Figure A translates typical converter-performance characteristics into line speed and pull. It shows the desired operating range between the points of 70% converter efficiency. The maximum continuous operating line pull should not exceed 55% of the stall pull. At this point, line speed will be 26% of the maximum no-load speed quoted in manufacturers' literature. For example, a yarder rated at 400 000 N bare-drum stall line pull will not function above 220 000 N bare-drum pull within the normal operating range. This will drop to 160 000 N or less as the drum becomes full and the spooling radius increases.

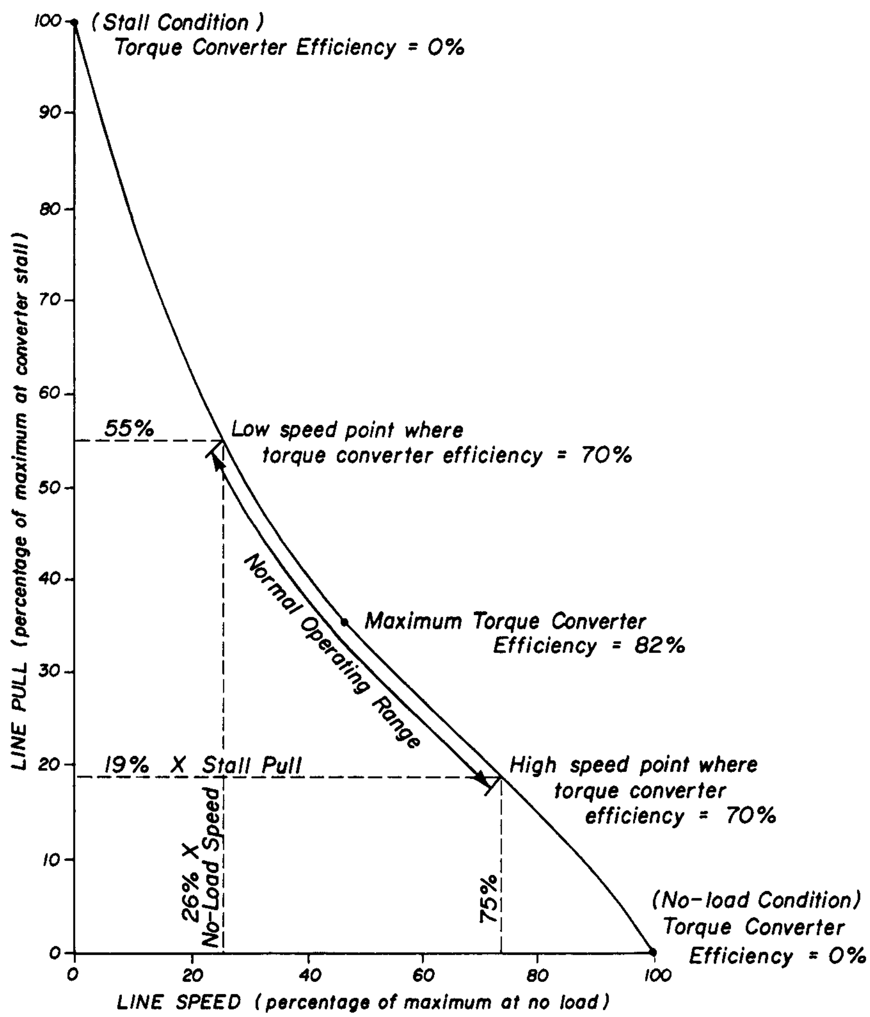


FIGURE A. Typical Performance Characteristics of a Torque Converter-Driven Winch.

A hydraulic drive produces a different line pull and speed characteristic, as shown in Figure B. The performance determinants are the available horsepower, the hydraulic efficiency, the maximum hydraulic pressure, and the maximum size and speed of the components. Figure B indicates that an effective line speed is attainable at, or just below, the maximum line pull. The higher rated line pull for the converter-driven winch of Figure A does not translate into superior performance within the normal operating range.

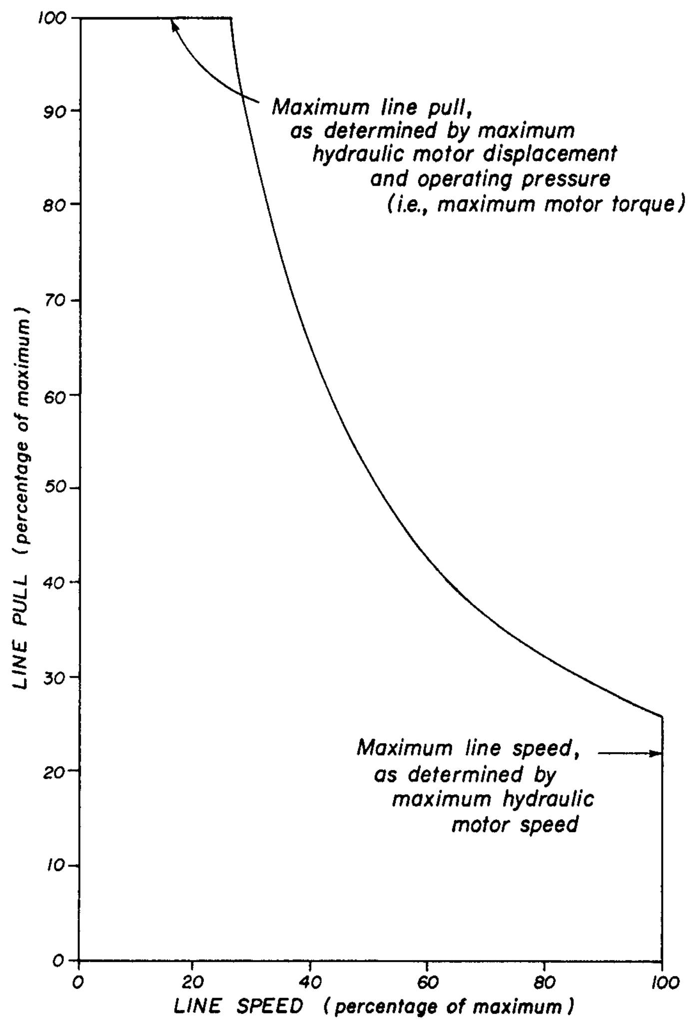
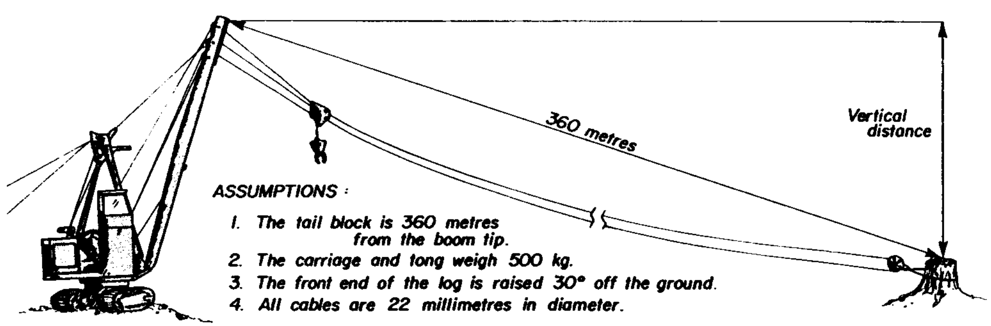


FIGURE B. Typical Performance Characteristics of a Hydraulically Powered Winch.

Another area of concern is how much line pull is actually needed in a yarding crane. To answer this, FERIC has combined information published by Mifflin and Mann in the September 1980 issue of Journal of Logging with a paper prepared in 1984 by Hartsough, Miles, and Bark of the University of California. The results are shown in Table 3. It indicates that a midspan mainline pull of 220 000 to 240 000 N and a haulback tensioning capability of 130 000 to 145 000 N is reasonable for typical coastal conditions.

TABLE 3. Line Tension Analysis for a Running Skyline with the Carriage at Midspan.

LOAD (kg)	DEFLEC.	LINE	0	20	40	60	80	100	120	140	160	180	200	220	240
			VERTICAL DISTANCE FROM FAIRLEAD TO TAIL BLOCK (m) — LINE PULL AT MIDSPAN (N)												
1000	2.00%	Main & Slack	129 384	130 204	131 502	133 301	135 640	138 580	142 207	146 642	152 059	158 702	166 933	177 298	190 666
		Haulback	122 102	122 466	123 309	124 653	126 537	129 021	132 191	136 171	141 131	147 318	155 093	165 003	177 915
	3.00%	Main & Slack	88 301	89 043	90 102	91 494	93 244	95 394	97 999	101 143	104 938	109 551	115 220	122 310	131 400
		Haulback	80 977	81 264	81 869	82 805	84 101	85 795	87 945	90 633	93 973	98 130	103 343	109 978	118 613
2000	3.00%	Main & Slack	118 998	119 818	121 105	122 882	125 190	128 091	131 674	136 065	141 445	148 072	156 328	166 793	180 400
		Haulback	104 455	104 822	105 656	106 980	108 834	111 281	114 410	118 347	123 273	129 445	137 246	147 256	160 409
	4.00%	Main & Slack	92 246	93 010	94 121	95 599	97 472	99 788	102 613	106 043	110 212	115 314	121 635	129 611	139 940
		Haulback	77 647	77 960	78 621	79 648	81 070	82 934	85 307	88 285	92 001	96 650	102 517	110 039	119 915
3000	4.00%	Main & Slack	116 656	117 481	118 765	120 533	122 825	125 704	129 261	133 625	138 980	145 591	153 848	164 351	178 063
		Haulback	94 829	95 205	96 041	97 360	99 203	101 634	104 741	108 656	113 561	119 720	127 526	137 577	150 836
	5.00%	Main & Slack	96 917	97 698	98 843	100 373	102 319	104 732	107 685	111 281	115 667	121 054	127 756	136 251	147 310
		Haulback	75 015	75 352	76 053	77 139	78 641	80 610	83 118	86 268	90 207	95 146	101 399	109 444	120 053
4000	4.00%	Main & Slack	141 066	141 952	143 409	145 467	148 177	151 620	155 909	161 208	167 749	175 868	186 062	199 092	216 187
		Haulback	112 010	112 449	113 460	115 072	117 337	120 333	124 176	129 028	135 121	142 791	152 534	165 114	181 758
	5.00%	Main & Slack	117 566	118 398	119 683	121 445	123 727	126 590	130 127	134 469	139 802	146 393	154 640	165 153	178 913
		Haulback	88 423	88 813	89 658	90 981	92 822	95 246	98 342	102 242	107 131	113 278	121 079	131 144	144 455
5000	5.00%	Main & Slack	138 215	139 098	140 522	142 518	145 134	148 447	152 569	157 657	163 936	171 731	181 524	194 054	210 516
		Haulback	101 831	102 275	103 264	104 823	107 003	109 881	113 566	118 216	124 056	131 409	140 758	152 843	168 857
	6.00%	Main & Slack	120 135	120 975	122 262	124 021	126 293	129 142	132 660	136 980	142 289	148 856	157 084	167 590	181 367
		Haulback	83 636	84 046	84 906	86 238	88 083	90 505	93 596	97 486	102 363	108 496	116 287	126 351	139 684
6000	5.00%	Main & Slack	158 865	159 798	161 362	163 590	166 541	170 305	175 011	180 845	188 071	197 070	208 408	222 955	242 118
		Haulback	115 238	115 737	116 869	118 665	121 184	124 516	128 790	134 190	140 980	149 541	160 438	174 542	193 259
	6.00%	Main & Slack	138 288	139 171	140 576	142 529	145 080	148 303	152 307	157 247	163 341	170 909	180 421	192 603	208 626
		Haulback	94 531	94 990	95 973	97 505	99 635	102 437	106 020	110 535	116 203	123 341	132 420	144 164	159 745



ASSUMPTIONS :

1. *The tail block is 360 metres from the boom tip.*
2. *The carriage and tong weigh 500 kg.*
3. *The front end of the log is raised 30° off the ground.*
4. *All cables are 22 millimetres in diameter.*

THE DIFFERENTIAL-INTERLOCK CONCEPT

The high energy efficiency of the FERIC design is attributable to the differential-interlock concept. A differential interlock is best analogized by an automotive differential axle assembly with a pair of drums mounted in place of the two wheels, as shown in Figure C. Let us consider one drum to be the haulback and the other the main. Torque, applied to the drive shaft, is transmitted equally to the two drums, tensioning the two lines. This tensioning will provide lift to the rigging as in a simple highlead configuration. A second power source capable of driving the main drum in either direction moves the rigging in and out.

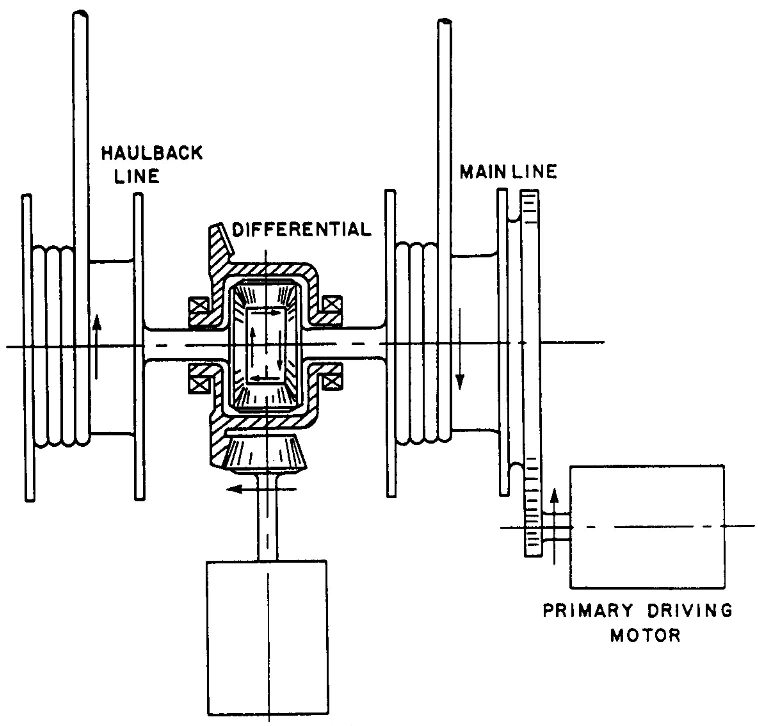


FIGURE C. Analogy of a Differential Interlock.

As the rigging comes in, the unspooling haulback line drives the haulback drum. The differential gearing transmits this power and uses it to help the primary driving motor drive the main drum. The differential interlock does not require a slipping clutch to compensate for the constantly changing relative speeds of the two drums. Instead, the differential provides this compensation as the tensioning motor drives it in either direction. When the working radius on the haulback drum is greater than that on the main drum, its speed will be slower than that of the main drum. Movement of the differential will cause the tensioning motor to rotate in one direction. As the mainline spools in, the main-drum working radius becomes larger than that on the haulback drum. The rotation of the tensioning motor will change direction. While the two working radii are the same, the two drums will rotate at the same speed but in opposite directions. There will be no rotation of the tensioning motor. It will only apply a static torque to keep the two lines tensioned.

The crown and pinion are required to transmit power in either direction. The hydraulic tensioning motor will supply power as the gears rotate in one direction. As the direction of rotation changes, the tensioning motor will absorb power and become a hydraulic pump. The tensioning motor is hydraulically connected to the primary driving motor and the diesel motor. The bi-directional flow of power is balanced against the power flowing from the haulback drum through the differential.

The net result of this complex system of interrelated power trains is the maximum utilization of available energy to move the log. Unlike the non-interlock or regenerative-interlock machines, there are no slipping-friction devices to waste valuable power. The winch provides faster line speed with a smaller engine.

DESIGN OF THE MACHINE

There are many combinations of drum dimensions, gear ratios, available power, and hydraulic system characteristics one must consider when designing a differential-interlock winch and predicting its performance. In addition, the distance of the rigging from the landing, the positioning of the tailblock, and the combinations of mainline and haulback-line pulls will affect performance. To handle this complexity efficiently, FERIC produced a computer model to predict performance under the various combinations. The model also allowed comparisons with the performance of hypothetical non-interlock and regenerative-interlock winches of the same class. Table 4 shows the results of the computer model. The regenerative-interlock and non-interlock winches operate within the parameters shown, while maintaining a minimum 70% efficiency on the three-stage converter. All three yarders have identical drums.

Table 4 demonstrates the efficiency of differential-interlock winches. Although the differential-interlock winch consumes 28% less power, it develops an average of 10% more line speed than the regenerative-interlock winch. This is based on those sections of Table 4 most representative of normal yarding conditions.

Several changes were made as the design moved from its initial to final stages. In the first design, shown in Figure D, the use of a torque-converter drive was considered. FERIC believed a torque converter would have greater acceptance in the industry than a hydraulic drive. However, such an arrangement created a need for reversing and multiple-speed clutches. This, added to the complexity of the differential components, outweighed any advantages of acceptability. Also, it was difficult to justify a converter drive because of the performance factors discussed previously.

The second design used a hydraulic drive. FERIC recognized that the introduction of hydraulic drives on yarding machinery represented a relatively new departure in this area. However, other industries have benefited from recent advances in this technology. This is particularly true in Europe where high-pressure hydraulics and hydrostatic drives have become commonplace. Although North America lags in the technology, the components are becoming more plentiful. The advantages of a hydraulic drive are the elimination of clutches and gearing, and the resultant simplification of operator controls.

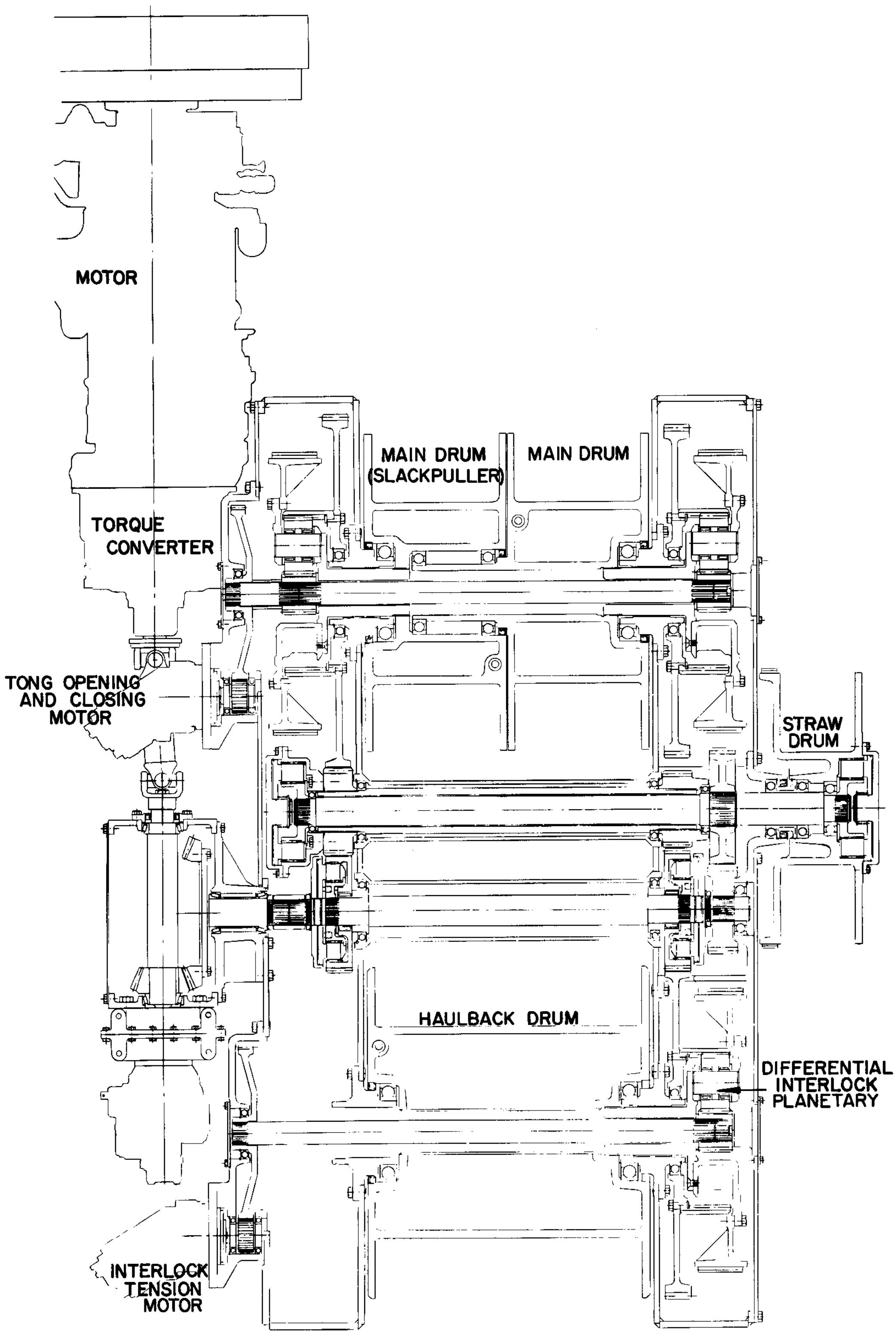


FIGURE D. Converter Driven Differential-Interlock Yarder.

TABLE 4. Comparative Line Speeds (m/min) for a Differential-Interlock Yarder, a Regenerative-Interlock Yarder, and a Non-Interlock Yarder.

DRUM DATA	MAIN	HAULBACK
Barrel dia. (mm)	610	610
Flange dia. (mm)	990	990
Inside width (mm)	360	810
Cable dia. (mm)	22	22
Max. no. of wraps	9	9
Max. capacity (m)	370	832

DIFFERENTIAL-INTERLOCK YARDER DATA	
Number of teeth in the sun gear	19
Number of teeth in the ring gear	77
Ratio haulback gear to main gear	1.00
Main motor to main gear ratio	12.65
Interlock motor to sun ratio	6.79
Engine net power (kW)	242
Main drive motor	
Max. speed (rpm)	2500
Max. displacement (mm^3)	936
Min. displacement (mm^3)	270
Interlock motor	
Max. speed (rpm)	2500
Max. displacement (mm^3)	468
Oil flow = 870 L/min @ 31050 kPa	

REGENERATIVE- AND NON-INTERLOCK YARDER DATA	
Low to high range transmission ratio	3.00
Haulback/main interconnecting gear ratio	1.45
Converter output to main drum ratio	
Regenerative-interlock yarder	25.00
Non-interlock yarder	37.00
Both yarders are powered by a diesel motor driving a Twin Disc 11500 series, MS:340 converter and a two-speed transmission.	
Net converter input power (kW)	336

LINE PULL (N) MAIN	LINE PULL (N) HAULBACK	YARDER TYPE	0	30	60	90	120	150	180	210	240	270	300	330	360
			DISTANCE FROM THE LANDING TO THE TURN (m) — LINE SPEED (m/min)												
48 000	24 000	Differential	338	338	352	352	357	354	354	350	348	345	345	340	337
		Regenerative	339	339	355	355	365	385	385	385	383	378	378	376	368
		Non-interlock	285	285	288	288	291	276	276	271	264	257	257	250	241
72 000	24 000	Differential	182	182	186	186	187	186	186	185	185	184	184	182	182
		Regenerative	183	183	184	184	190	199	199	209	216	224	224	237	248
		Non-interlock	169	169	172	172	174	177	177	179	182	185	185	188	191
96 000	24 000	Differential	124	124	126	126	127	126	126	126	126	125	125	125	124
		Regenerative	154	154	153	153	151	148	148	146	142	139	139	147	154
		Non-interlock	122	122	119	119	118	120	120	123	125	127	127	130	132
120 000	24 000	Differential	95	95	96	96	96	96	96	95	95	95	95	95	94
		Regenerative	120	120	122	122	125	128	128	131	124	122	122	120	116
		Non-interlock	109	109	107	107	104	102	102	99	96	94	94	96	98
72 000	48 000	Differential	297	297	319	319	327	321	321	315	311	308	308	300	295
		Regenerative	222	222	238	238	248	269	269	294	311	331	331	339	340
		Non-interlock	169	169	172	172	174	177	177	179	182	185	185	188	191
96 000	48 000	Differential	169	169	176	176	179	177	177	175	174	173	173	170	169
		Regenerative	165	165	164	164	162	159	159	167	175	185	185	203	217
		Non-interlock	122	122	119	119	118	120	120	123	125	127	127	130	132
120 000	48 000	Differential	118	118	122	122	123	122	122	121	121	120	120	119	118
		Regenerative	134	134	139	139	142	138	138	137	135	132	132	130	139
		Non-interlock	109	109	107	107	104	102	102	99	96	94	94	96	98
144 000	48 000	Differential	91	91	93	93	94	93	93	93	92	92	92	91	91
		Regenerative	102	102	106	106	108	112	112	117	120	116	116	116	113
		Non-interlock	95	95	96	96	97	92	92	90	88	86	86	83	80
96 000	72 000	Differential	265	265	291	291	302	294	294	286	282	277	277	268	263
		Regenerative	177	177	176	176	181	201	201	224	240	260	260	304	312
		Non-interlock	122	122	119	119	118	120	120	123	125	127	127	130	132
120 000	72 000	Differential	158	158	167	167	171	168	168	166	164	163	163	159	157
		Regenerative	151	151	150	150	148	149	149	148	145	156	156	176	192
		Non-interlock	109	109	107	107	104	102	102	99	96	94	94	96	98

TABLE 4 continued

LINE PULL (N) MAIN	HAULBACK	YARDER TYPE	0	30	60	90	120	150	180	210	240	270	300	330	360
			DISTANCE FROM THE LANDING TO THE TURN (m) — LINE SPEED (m/min)												
144 000	72 000	Differential	113	113	117	117	119	118	118	117	116	115	115	113	112
		Regenerative	113	113	118	118	122	128	128	128	128	126	126	125	126
		Non-interlock	95	95	96	96	97	92	92	90	88	86	86	83	80
168 000	72 000	Differential	88	88	90	90	91	91	91	90	90	89	89	88	87
		Regenerative	88	88	92	92	95	100	100	105	109	113	113	111	110
		Non-interlock	78	78	79	79	80	81	81	82	83	79	79	77	75
120 000	96 000	Differential	238	238	268	268	280	271	271	262	258	253	253	242	236
		Regenerative	159	159	161	161	159	160	160	178	193	211	211	253	287
		Non-interlock	109	109	107	107	104	102	102	99	96	94	94	96	98
144 000	96 000	Differential	148	148	159	159	164	161	161	157	156	154	154	150	148
		Regenerative	126	126	134	134	139	138	138	140	138	136	136	154	171
		Non-interlock	95	95	96	96	97	92	92	90	88	86	86	83	80
168 000	96 000	Differential	108	108	113	113	116	114	114	112	112	111	111	109	107
		Regenerative	97	97	102	102	106	113	113	121	120	120	120	121	120
		Non-interlock	78	78	79	79	80	81	81	82	83	79	79	77	75
192 000	96 000	Differential	85	85	88	88	89	88	88	87	87	86	86	85	84
		Regenerative	77	77	82	82	84	89	89	95	99	104	104	107	107
		Non-interlock	66	66	67	67	68	68	68	69	70	71	71	72	69
144 000	120 000	Differential	217	217	248	248	261	252	252	242	237	232	232	221	215
		Regenerative	141	141	153	153	146	149	149	151	159	176	176	215	248
		Non-interlock	95	95	96	96	97	92	92	90	88	86	86	83	80
168 000	120 000	Differential	140	140	152	152	157	154	154	150	148	146	146	142	139
		Regenerative	107	107	114	114	119	129	129	131	131	130	130	136	154
		Non-interlock	78	78	79	79	80	81	81	82	83	79	79	77	75
192 000	120 000	Differential	103	103	110	110	112	110	110	109	108	106	106	104	103
		Regenerative	84	84	90	90	93	100	100	108	114	114	114	117	116
		Non-interlock	66	66	67	67	68	68	68	69	70	71	71	72	69
216 000	120 000	Differential	82	82	86	86	87	86	86	85	84	84	84	82	81
		Regenerative	68	68	73	73	75	81	81	87	91	96	96	105	104
		Non-interlock	56	56	57	57	58	59	59	60	61	62	62	63	64
168 000	144 000	Differential	199	199	231	231	245	235	235	225	220	214	214	203	197
		Regenerative	118	118	129	129	135	138	138	142	142	149	149	186	217
		Non-interlock	78	78	79	79	80	81	81	82	83	79	79	77	75
192 000	144 000	Differential	132	132	146	146	151	147	147	143	141	139	139	134	131
		Regenerative	92	92	99	99	104	113	113	125	124	124	124	127	139
		Non-interlock	66	66	67	67	68	68	68	69	70	71	71	72	69
216 000	144 000	Differential	99	99	106	106	109	107	107	105	104	103	103	100	98
		Regenerative	74	74	79	79	83	90	90	98	104	110	110	113	113
		Non-interlock	56	56	57	57	58	59	59	60	61	62	62	63	64
240 000	144 000	Differential	79	79	84	84	85	84	84	83	82	81	81	80	79
		Regenerative	61	61	65	65	68	73	73	79	84	89	89	99	101
		Non-interlock	49	49	50	50	50	51	51	52	53	54	54	55	56

FERIC also considered different positioning of the drums. Figure E shows the haulback drum flanked by the main drum and the slackpuller drum. All drums were mounted on a common shaft. This arrangement simplified the means of transferring interlock power. Utilization of a standard road-wheel planetary provided the differential-assembly, as well as the main-drum bearing, requirement.

Throughout the design phase, consultation continued with manufacturers and the logging industry. A meeting was held in August, 1985, with logging-industry personnel to discuss the whole concept. After some discussion on the relative merits of the differential- versus the regenerative-interlock principle, the group focussed on winch configuration. Although those present agreed that the in-line configuration offered simplicity, they considered it defective in terms of the operator's visibility of the drums. Also, proper spooling of the two outside drums would involve passing the lines over blocks mounted at the top of the gantry. They would then pass through fairleads mounted at the top of the boom. The group considered these extra blocks a source of undesirable line wear. They felt that a more conventional drum configuration would achieve better performance with little sacrifice of simplicity. Other factors discussed were the need for a large drum-core to line-diameter ratio, good accessability for easy maintenance, and the merits of making the winch compatible with a variety of carriers.

Figure F shows the final arrangement of the FERIC yarding crane concept. Figures G and H show how this assembly is adapted to the carrier and machinery deck of a Caterpillar 245 excavator. This winch assembly is easily adaptable to other carriers of similar size, such as the Chapman 1825. It is driven by approximately 242 kW through a variable displacement pumping system with a maximum system pressure of between 31 000 and 38 000 kPa.

The winch arrangement shown in Figure F consists of two planetary road-wheel hubs mounted inside the core of the haulback drum. Two variable-displacement motors drive the sun gears of these planetaries. They tension the haulback line, and determine the amount of torque transmitted through the planetaries to the main drum and the slackpuller drum. These motors are analogous to the tensioning motor shown in Figure C. Two more variable-displacement motors drive the main drum and slackpuller drum. These are analogous to the primary driving motors shown in Figure C. The carrier supplies hydraulic oil at relatively constant pressure. Volume is determined by power requirements and the displacement of the motors.

To initiate the inhaul sequence, the operator increases displacement of the main motors and thus increases main and slackpuller line pull. Simultaneously, displacement of the two interlock tension motors is regulated. This determines the level of haulback line tension and the amount of interlock torque transmitted to the main and slackpuller drums.

The interlock tension motors are connected in series to the main oil supply. An equal displacement on these motors will ensure equal speeds within the planetaries and thus equal speeds of the main and slackpuller drums.

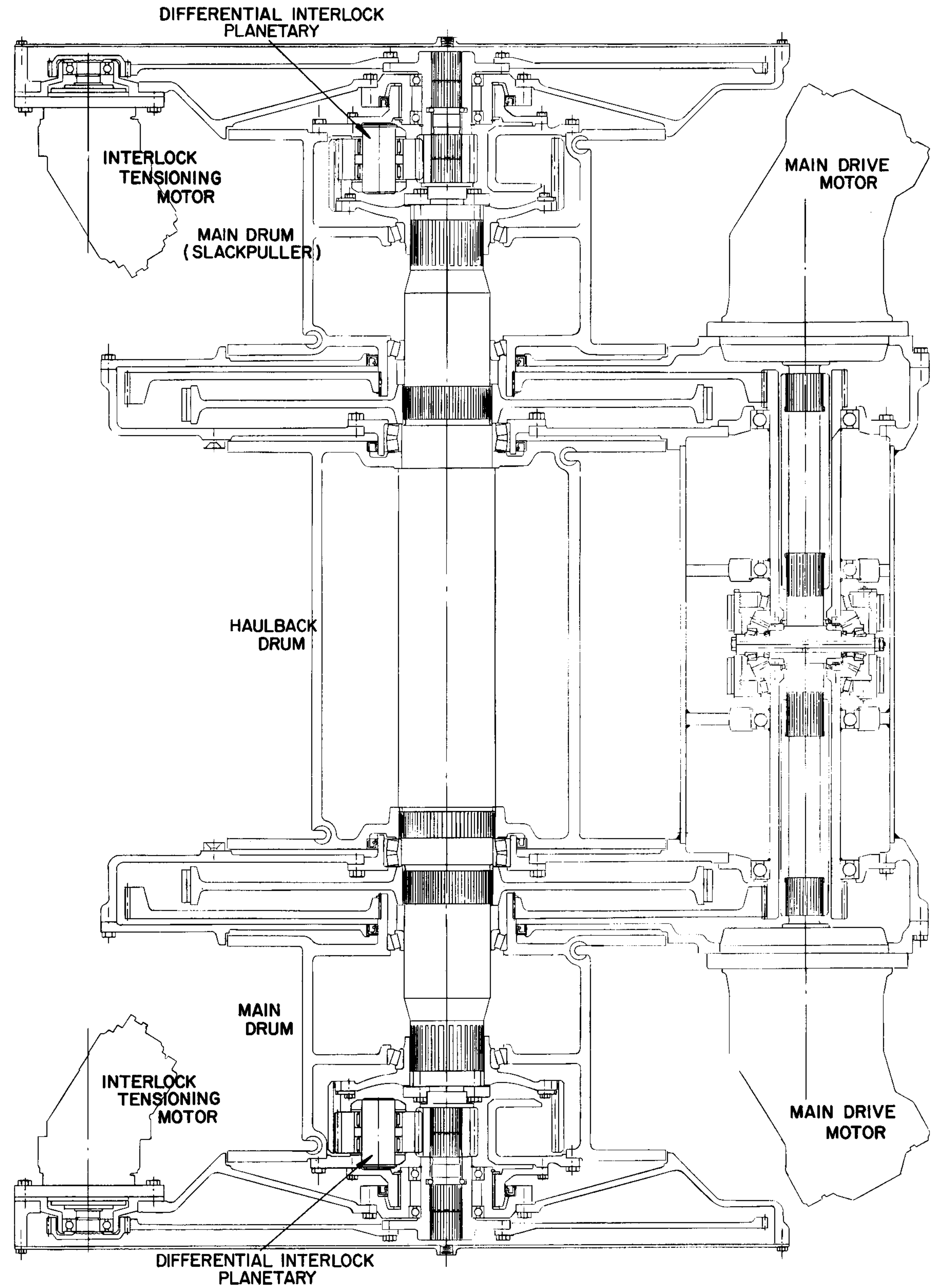


FIGURE E. Hydraulically Driven Differential-Interlock Yarder.
All drums are on one shaft.

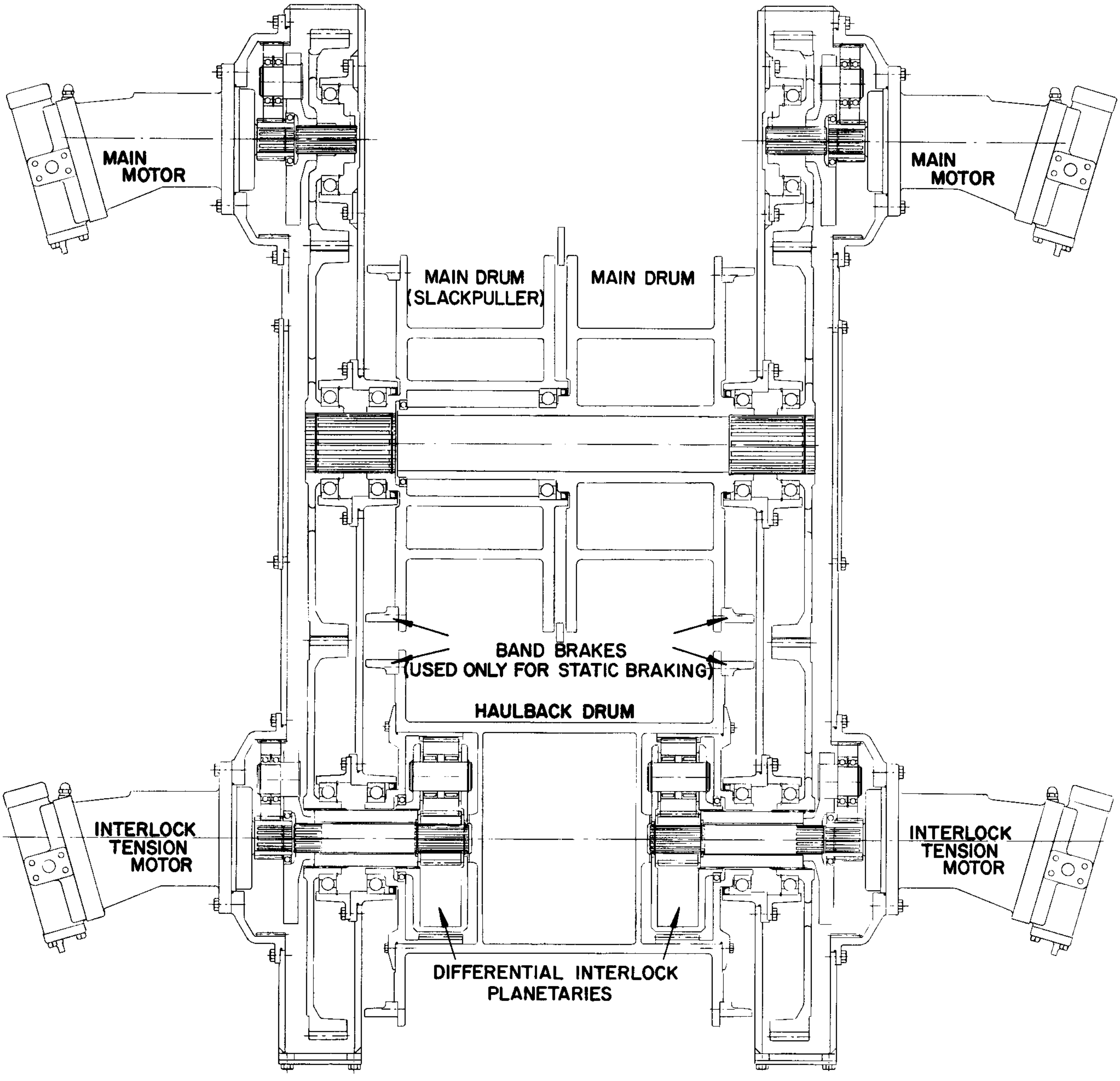


FIGURE F. Differential-Interlock Yarder.

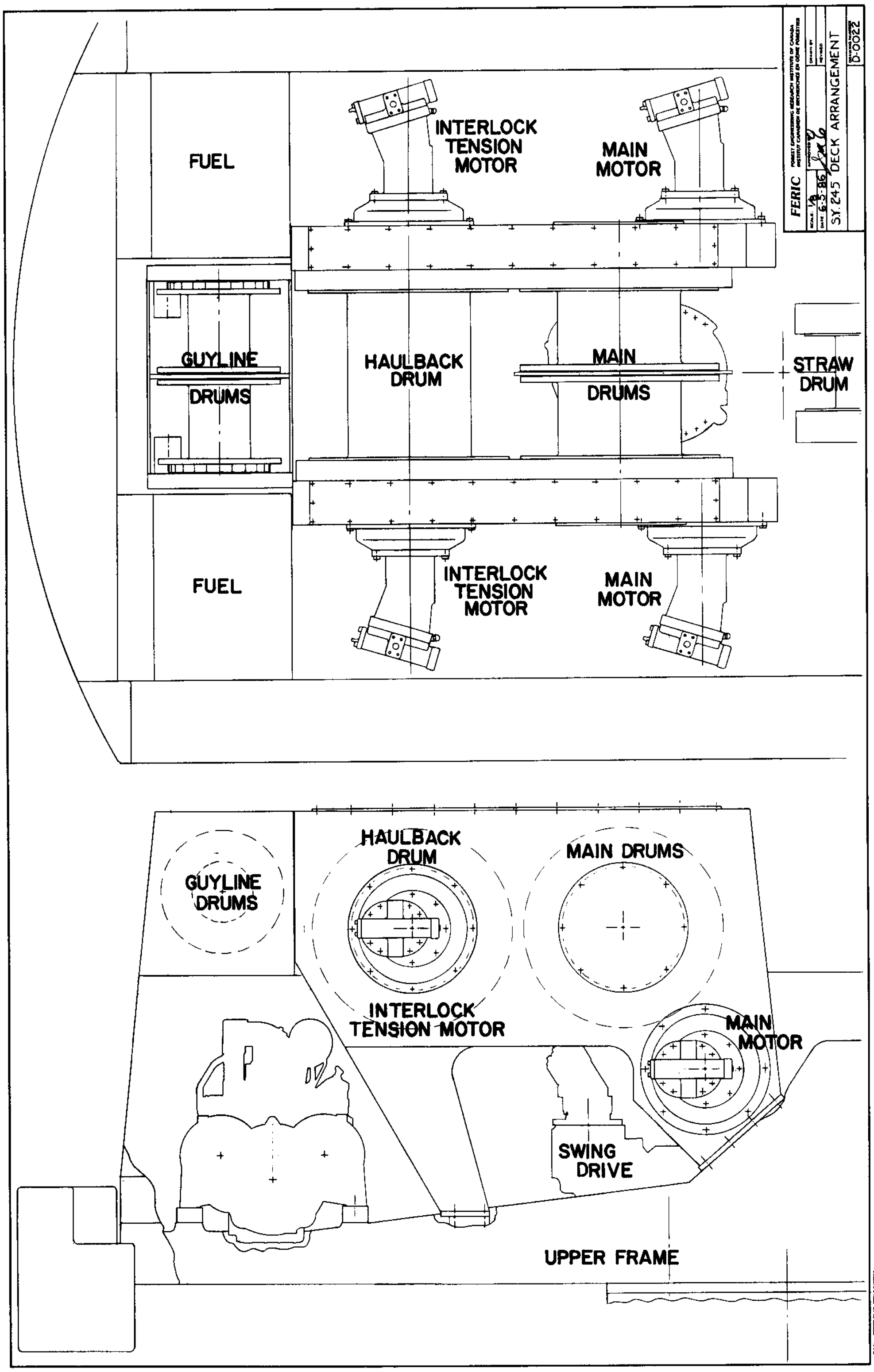


FIGURE G. Machinery Deck Assembly.

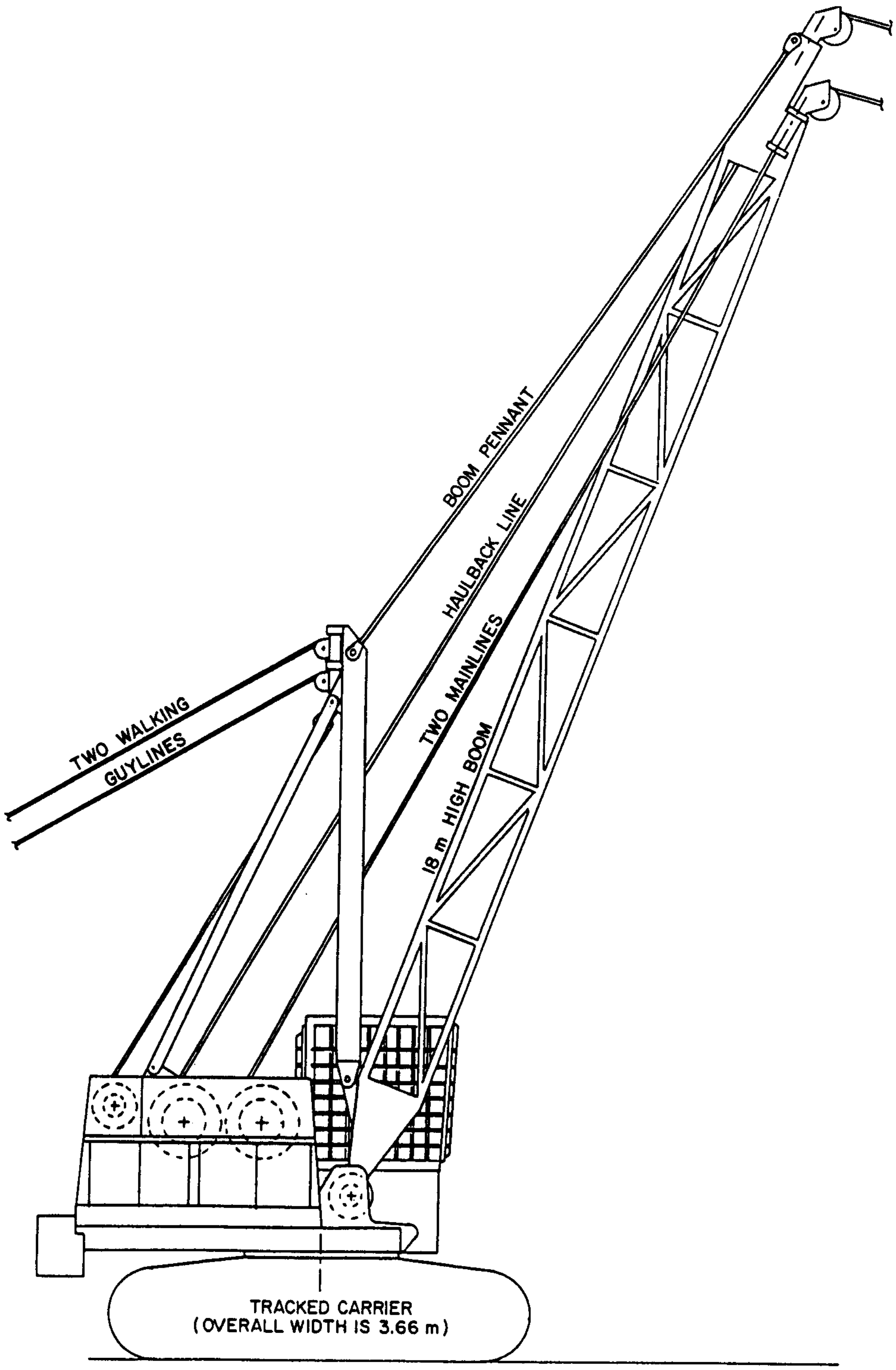


FIGURE H. Complete Yarding Crane Assembly.

To manipulate a grapple or control a drop line, the main and slackpuller drums must rotate at different speeds. This is achieved by a small pump superimposing a secondary flow, or bias, on the series connection between the interlock tension motors. The resulting unequal motor speed will produce the desired change of drum speeds.

The main motors are connected to the main oil supply in parallel. Control of the relative displacements of these motors will help determine relative tension in the main and slackpuller lines. Relative speeds of these motors are tied into the speeds of the main and slackpuller drums as determined by the interlock tension motors.

The operator controls all winch functions, plus the swing function, through two main joystick levers. The band brakes, shown on each drum, are used only for stopping the drum and, in the case of the haulback drum, holding it during shotgun application. They are not required for dynamic braking. The winch and the controls are also adaptable to standard highlead and shotgun yarding.

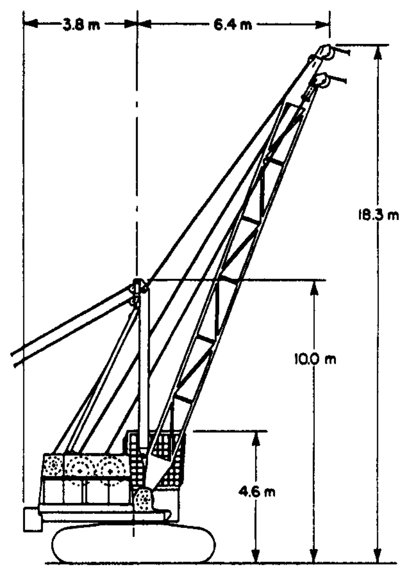
The winch has several features which will help in manufacturing and field maintenance. All four motors and their adjacent planetary reductions are similar or identical. The four bull gears, as well as the two pinions that drive them, are the same. The bull gears are designed to be manufactured from low-cost ductile iron without subsequent heat treating. The major drum bearings and the bearing supporting the main pinions are the same. The housings that support these bearings and the oil seals on all the drums are also the same. All the gearing is contained in sealed compartments and is bath lubricated. In spite of this containment, the main spur gear drive assembly is easily accessed through a top opening. It may be removed by first dismounting either the appropriate motor assembly or the cover plate at the end of the drums. Once the gears are removed, the drum-bearing assemblies may be unbolted and the drums removed.

Figure I is a specification sheet for the final product.

COST EFFICIENCY

At this stage of development, a cost analysis of the machine is somewhat speculative. However, there are several cost savings that are obvious and should be achievable in practice. One money-saving feature relates to the carrier. The winch assembly may be retrofitted to a used carrier assembly. Alternatively, a new carrier may be customized by the removal of the boom and other unwanted components. Either of these options would result in a cost saving by using mass-produced components. Additional advantages would exist in after-sales service. The simplicity of the winch and the commonality of components will also contribute to the economy of manufacturing. The cost of hydraulics is offset by the elimination of clutches, brakes, and the extra gearing required for speed and direction changes. Ductile iron is used extensively throughout this assembly and particularly in the gearing. It is cheaper than steel castings and is easier to machine. As mentioned previously, the hydraulic drive and differential interlock result in a lower torque and power requirement in many components.

Drive-train components for the converter-driven machine must withstand maximum stall torque. The absence of this, in the new design, results in smaller components and additional cost savings. FERIC estimates that the new yarding crane would cost $100 000 less than an equivalent regenerative-interlock crane.



Power:	242 kW at 2100 rpm
Hydraulic System:	Maximum pressure--31 050 kPa Maximum flow--870 L/min
Main Yarder Drive Motors:	Two variable-displacement piston motors connected in parallel having a combined displacement range of 270 to 936 mm³.
Interlock Motors:	Two variable displacement piston motors connected in series having an effective displacement range of 135 to 468 mm³.
Carrier:	Hydraulically driven tracked carrier Maximum speed--4 km/h Maximum width--3.66 m
Swing:	Hydraulically driven slewing ring mount Maximum speed--6 rpm
Yarder Controls:	Normal operation of all yarding functions is achieved through two joystick levers. The left-hand lever controls swing and interlock tension. The right-hand lever controls the grapple opening and closing, and the direction and speed of rigging movement.
Fuel Capacity:	1140 L
Machine Weight:	65 000 kg

Drum	Capacity (m)	Maximum Speed (m/min)		Maximum Pull (N)	
		Full Drum	Empty Drum	Full Drum	Empty Drum
Main	370	605	365	300 000	430 000
Slackpuller	370	605	365	300 000	430 000
Haulback	832	755	455	140 000	215 000
Straw	1000	150	60	20 000	50 000

FIGURE I. Specifications for the Differential-Interlock Yarding Crane.

Table 5 shows operating cost estimates for equivalent differential-interlock, regenerative-interlock, and non-interlock machines. The differential-interlock machine provides an estimated cost saving per turn of 11% relative to the regenerative-interlock yarder. Twenty-one percent of this saving is attributable to the higher line speeds. The remainder is attributable to the lower operating and capital costs.

TABLE 5. Ownership and Operating Costs (excluding interest).

	YARDER TYPE		
	DIFFERENTIAL INTERLOCK	REGENERATIVE INTERLOCK	NON-INTERLOCK
OWNERSHIP COSTS			
Purchase Price	$770 000	$870 000	$770 000
Salvage Value (20% of Purchase Price)	$154 000	$174 000	$154 000
Expected Life (yr)	5	5	5
Hours of Operation per Year	2 000	2 000	2 000
Expected Life (h)	10 000	10 000	10 000
Average Investment	$462 000	$522 000	$462 000
Insurance Rate (% of Average Investment)	5.00%	5.00%	5.00%
HOURLY OWNERSHIP COSTS			
Loss in Resale Value	$61.60	$69.60	$61.60
Insurance	$11.55	$13.05	$11.55
TOTAL	$73.15	$82.65	$73.15
OPERATING AND REPAIR COSTS			
Mainline 400 m of 22-mm dia. line	$2 860	$2 860	$2 860
Slackpuller 400 m of 22-mm dia. line	$2 860	$2 860	$2 860
Haulback 850 m of 22-mm dia. line	$6 160	$6 160	$6 160
Guylines	$1 700	$1 700	$1 700
Straw	$1 200	$1 200	$1 200
Line Life (h)	1 500	1 550	1 770
Rigging Costs	$10 000	$10 000	$10 000
Rigging Life (h)	1 500	1 550	1 770
Fuel Consumption (L/h)	29	40	40
Fuel Costs ($/L)	$0.36	$0.36	$0.36
Annual Repair & Maintenance (10% of the Price)	$77 000	$87 000	$77 000
HOURLY OPERATING AND REPAIR COSTS			
Line Costs	$9.85	$9.54	$8.35
Rigging Costs	$6.67	$6.45	$5.65
Fuel Costs	$10.44	$14.40	$14.40
Lube and Oil Costs (15% of the Fuel Costs)	$1.57	$2.16	$2.16
Repair and Maintenance Costs	$38.50	$43.50	$38.50
Wages ($/h)	$50.00	$50.00	$50.00
TOTAL	$117.03	$126.05	$119.06
TOTAL HOURLY OPERATING COSTS	$190.18	$208.70	$192.21
MACHINE PERFORMANCE[1]			
Average Yarding Speed In (m/min)	204	186	122
Average Yarding Speed Out (m/min)	411	381	274
Inhaul Time (min)	0.672	0.738	1.125
Unhook Time (min)	0.300	0.300	0.300
Outhaul Time (min)	0.333	0.360	0.500
Hookup Time (min)	0.650	0.650	0.650
Road Changes, Maintenance, etc. (min)	1.500	1.500	1.500
TOTAL TIME PER TURN (min)	3.455	3.548	4.075
COST PER TURN ($)	$10.95	$12.34	$13.05

[1]Assume Average Yarding Distance = 137 m.

CONCLUSIONS

The concept of a hydraulically driven differential-interlock yarder, mounted on a mass-produced carrier, has been proven with the S.Y. 235. The coastal market could benefit from this same technology in a machine having 240 000 N mainline pull. West Coast owners and operators are facing a trend towards longer yarding distances, poorer deflection, and heavier turns. The FERIC concept addresses these requirements with a design featuring 10% more line speed and consuming 28% less power than conventional interlock machines. The potential savings in ownership and operating costs are estimated to be 11 percent. Extensive use of mass-produced assemblies will contribute to this saving and should facilitate better service and maintenance.

For a forest industry constantly striving to reduce costs, this new yarding crane concept holds significant potential. The fruition of this concept into a finished machine is dependent on the commitment of capital by the logging industry and by manufacturing. FERIC has dedicated considerable effort to developing this concept and is convinced of the benefits. FERIC will offer continued technical assistance, within the constraints of its mandate, to any party interested in seeing the concept to completion.