Sumitomo Drive Technologies

IMPLEMENTING THE SUMITOMO

BBB-H BEVEL GEARMOTOR LAFERT IE5 PM MOTOR AND INVERTEK VARIABLE FREQUENCY DRIVE

FOR AIRPORT BAGGAGE HANDLING CONVEYOR APPLICATION

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Implementing the Sumitomo BBB-H Bevel Gearmotor, Lafert IE5 PM Motor and Invertek Variable Frequency Drive for Airport Baggage-Handling Conveyor Application

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I. Introduction

Unit Material Handling (UMH) systems i.e. Airport Baggage Handling (ABH), Distribution Centers (DC), and Parcel Handling (PH) systems, of global demand are on the rise more so than most other industries. Sumitomo Drive Technologies, as a Power Transmission and Control Manufacturer, is now a solutions provider on several of the active expansion and replacement projects. In General, UMH applications are becoming more demanding, by way of requiring higher capability, higher control level, greater safety protocols, and most importantly higher efficiency to reduce the carbon footprint. Due to advancing economies, the world is getting smaller and the UMH industry is the benefactor of these changes. As a result of this global marketplace, component manufacturers must be properly positioned to complete on such as large platform. Hence, Sumitomo Drive Technologies has to be leading this innovation turning point by speeding up the development and improvement of its product portfolio.

This paper will present the test results of a series of stop-start tests conducted on the Sumitomo Drive Technologies' integral Bevel Buddy Box 'H' Series (**BBB-H)** IE3 Gearmotor, Lafert IE5 PM Motor, and Invertek VFD drive in April 2020. These tests were conducted in such a manner as to simulate the function of a Queue Conveyor and Transport Conveyor utilized in various strategic locations in ABH conveyor systems at many airports worldwide. The Queue Conveyor's requirement called for a series of one million very aggressive start-stop cycles, and Transportation Conveyor's requirement called for 0.3 million similarly harsh cyclic operation. It was decided to conduct a product feasibility analysis for such a cycle test for both (1) simulating the Queue Conveyor Test and (2) simulating the Transportation Conveyor Test. Queue Conveyor is one of frequently found applications within the various ABH systems. This is attributed to the function of the conveyor in respect the growing number of travelers transporting 'non-carry on' baggage. Queue Conveyors requires a specific quantitative algorithm for queuing baggage at a complimentary frequency and pace as passengers matriculating through the various airport terminals and gates. For example, the Duty Cycle / Speed Chart for Queue Conveyor utilized called for a ramp-up-operate-ramp-down-stop of approximately one seconds per cycle.

Figure 1 Typical Schematic of Airport Inline Screening System[i]

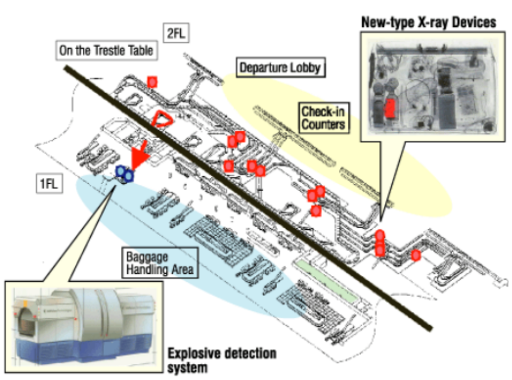


Figure 2 Inline EDS and Queue Conveyor[ii]

In 2018, Sumitomo Drive Technologies launched BBB-H gearmotor with IE3 EP.NA motor efficiency class. BBB-H is a two-stage speed reducer with a highly efficient bevel gear on the first stage and Spur gear on the second stage of reduction. Overall mechanical gear efficiency is greater than 93%[iii]. Recently Sumitomo Drive

Technologies acquired Lafert S.p.A. (Italy) and Invertek Drives Ltd. (UK). The strength of these latest acquisitions provides a reinforced product portfolio of motors and Variable Frequency Drives (VFD) that are unmatched matched in the market.

Lafert Group, European leader in the design and production of electric motors and drivers customized for industrial use.
Invertek Drives is also European leader in the design and production of variable frequency drives (VFD). With Sumitomo Group, both are global leaders together in the industrial automation field and expand our capability to approach to the entire airport application too.

Figure 3: Sumitomo BBB-H Gearmotor[iv]

Figure 4: Lafert Motors[v]

Figure 5: Invertek Drives[vi]

Taking on the challenge of this requirement locally SMA conducted a series of tests, which provided significant data for the BBB-H Gearmotor, Lafert IE5 PM Motor and Invertek VFD. The motor frame temperature data concluded that all drives met the requirement without excess temperature rise nor motor coil deterioration. Motor shaft voltage were inspected in great detail and found to be completely free from fluting or any other kind of unwanted effect from the VFD setup. The geared-components were examined per AGMA guidelines for any indication of wear or damage; none was found.

One of the reasons the BBB-H integral gearmotor can withstand such testing and come out with exceptional performance is because of its design features such as the use of bevel gears, as well as an optimum motor design with very low inertia compared to other manufacturers i.e. BBB-H three horsepower motors exhibit inertias on a magnitude of 1.8+ times less than other comparable motors. These and other features enabled the Sumitomo BBB-H Series integral gearmotor to truly perform exceptionally in these tests.
Conveyor manufacturers and end-users have various choices in selecting drives for their equipment, however, based on the data summarized in this report and the BBB-H optimal solution for the needs of the market.

II. A Challenging Specification

The typical ABH Queue conveyor manufacturers specification is as Table 1.

Table 1 Common Specification from 4 Airport Baggage Handling Conveyor Manufacturers[vii]

Dimensions	Conveyor Length	Ranges from 36" to 136"
	Conveyor Width	Ranges from 26" to 56" between frames
	Pulley Diameter	Various
Speed	Belt Speed	Variable (Ranges from 90-350 fpm)
	VFD Control	Typically Available
Driver	Motor	Various (Ranges from 3/4 HP to 3 HP, 3-phase AC-Induction Motor)
	Speed Reducer Type	Various (Helical bevel, helical shaft mounted, motorized pulley, belt drive, etc.)

In addition to the ‘hard’ specification, the application demands a drive systems that user friendly, operates error-free, and provides a robust performance with little to no maintenance requirements. These system factors can make the difference in an airport’s ability to attract and maintain major carriers, jobs, and income to the local community.

In 2009 Sumitomo Drive Technologies partnered with Diversified Conveyor Inc. (DCI) of Memphis, Tennessee, in their Queue Conveyor redesign initiative. The industry specification for which both DCI and Sumitomo tested were based on the following:

"*Supply queue conveyors of the manufacturers approved design capable of sustaining continuous stop/start operation at forty-five (45) cycles per minute under loaded conditions, and be capable of 60 cycles per minutes for durations of up to 15 minutes in an unloaded condition.*" [viii]

In this test setup both Sumitomo and DCI chose to simulate a worst-case scenario in which loading was applied at approx. 60 start-stop cycles per minute versus the less aggressive 45 start-stop cycle). Per the test duration requirement, the drive system and conveyor concluded after 1,000,000 cycles. This test simulation equates to the queue conveyor seeing 60 bags per minute continuously for approximately 12 days. The individual duty cycle / speed chart is shown in **Fig.9**.

As these are known information and experience, the 2020 test iteration, *See Example 1,* for the BBB-H gearmotor also followed the same concept and scenario.

Example 1: Queue Conveyor Modeling

Figure 6 Queue Conveyor Simulated Model Schematic

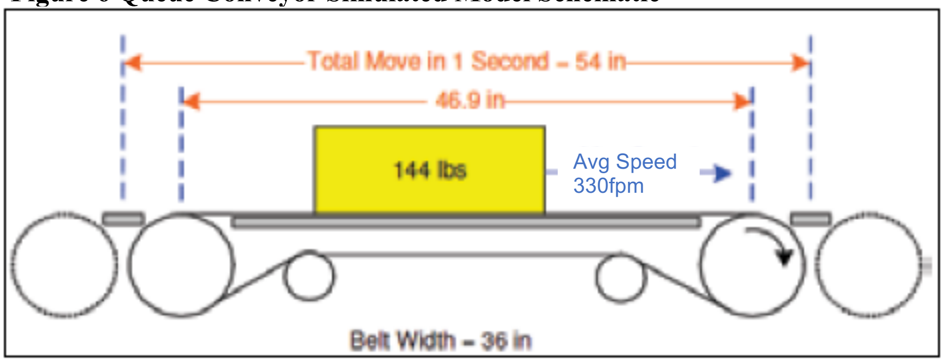
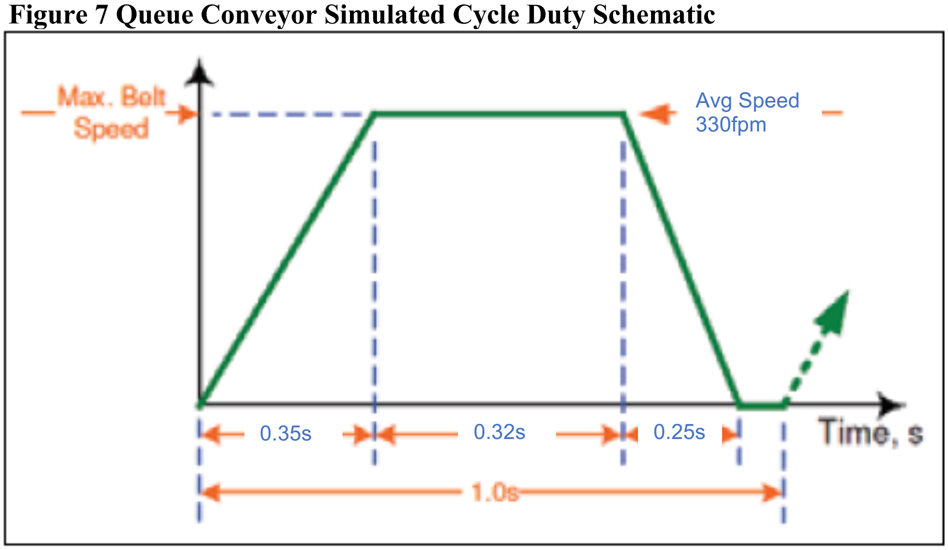


Figure 7 Queue Conveyor Simulated Cycle Duty Schematic



Example 2: Transportation Conveyor Modeling

Figure 8 Transport Conveyor Simulated Model Schematic

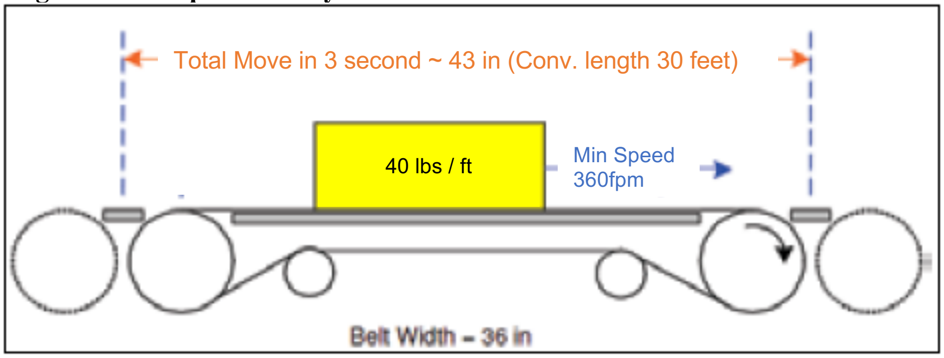
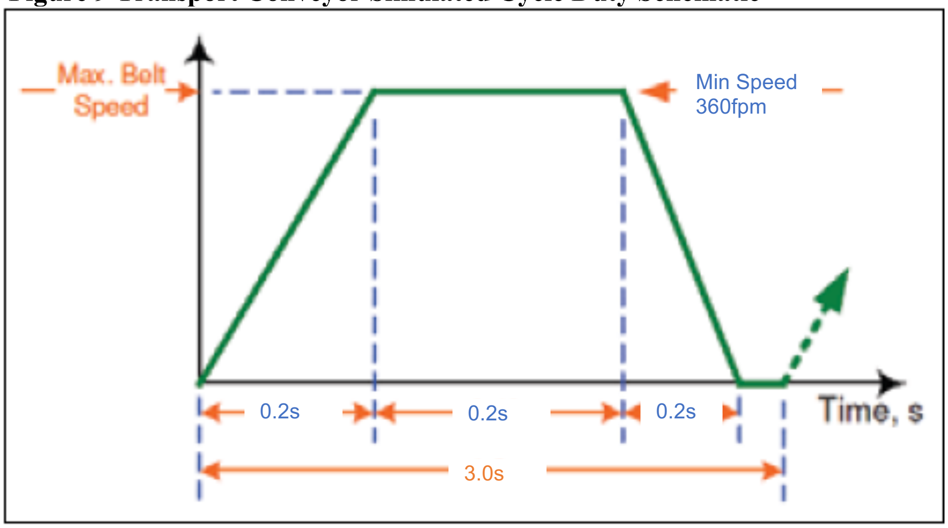


Figure 9 Transport Conveyor Simulated Cycle Duty Schematic



III. Testing Objectives and Methodology

The objective of simulation test was to 1) investigate and confirm the suitability of the BBB-H Gearmotor for the severe duty cycles encountered in various baggage handling related applications, and 2) replicate the rigorous demands of harsh cycles encountered in Queue Conveyors. These cycles subject the drive unit to frequent starts and stops thus creating a potential for severe Hertzian stresses and shock loading on the drive unit's torque transmitting teeth. The goal was to confirm that with proper selection and mounting to the conveyor; the Sumitomo BBB-H Series is a suitable and perhaps the ideal drive unit in these applications.

A second simulation test was to model the situation of Lafert IE5 PM motor and Invertek VFD to with stand a calculated load being transmitted from the Transport Conveyors. This application also has a harsh duty cycles, though commonly containing longer rest time (this time simulated 2.4sec out of 1 cycle 3.0sec) as showed in Figure 9. The Transport Converyor requires monitoring the performance on both motor and VFD combination. In this case the system was modeled and simulated without the gearboxes.

Testing was planned and conducted based on the following information:

Test 1: BBB-H Gearmotor to Simulate Queue Conveyor Test

Test Unit: **BBB-H Gearmotor Size #HZ522, Ratio 5:1**
Motor: Sumitomo 3HP 3Phase IE3 Induction Motor
Load Unit: Hyponic Gearmotor Size 1522#, Ratio 5:1 with Sumitomo 5HP IE3 motor
Controller: Koyo Direct Logic 06 – D0-06DR
VFD: Sumitomo VFD 7.5HP

➡ **Test based on Duty Cycle / Speed Chart, stopping at 1 million cycles to inspect mechanical parts and inspection will be documented.**

Reducer Duty Cycle Verification:

Criterion	Spec.	Selection
Accel Torque (0.35s)	659 in-lbs	630 in-lbs
Decel Torque (0.25s)	557 in-lbs	613.8 in-lbs
Root Mean Cubed Torque	490 in-lbs	504.1 in-lbs ✓

Test 2: Lafert IE5 PM Motor and Invertek VFD to Simulate Transport Conveyor Test

Test Unit: **Lafert IE5 PM Motor (2HP) - HPS 90 1800 32**

Load Unit: Sumitomo 10HP 3Phase IE3 Induction Motor
Controller: Koyo Direct Logic 06 – D0-06DR
VFD: **Invertek VFD 3HP - ODP-2-24030-3HF42-SN**

➡ **Test based on Duty Cycle / Speed Chart, stopping at 0.3 million cycles. Running data will be recorded and documented.**

Motor Duty Cycle Verification:

Criterion	Spec.	Selection
Accel Torque (0.2s)	187.2 in-lbs	179.1 in-lbs
Decel Torque (0.2s)	53.6 in-lbs	77.2 in-lbs
Root Mean Cubed Torque	85.9 in-lbs	98.0 in-lbs ✓

(shows only motor torque as simulated scaled down test)

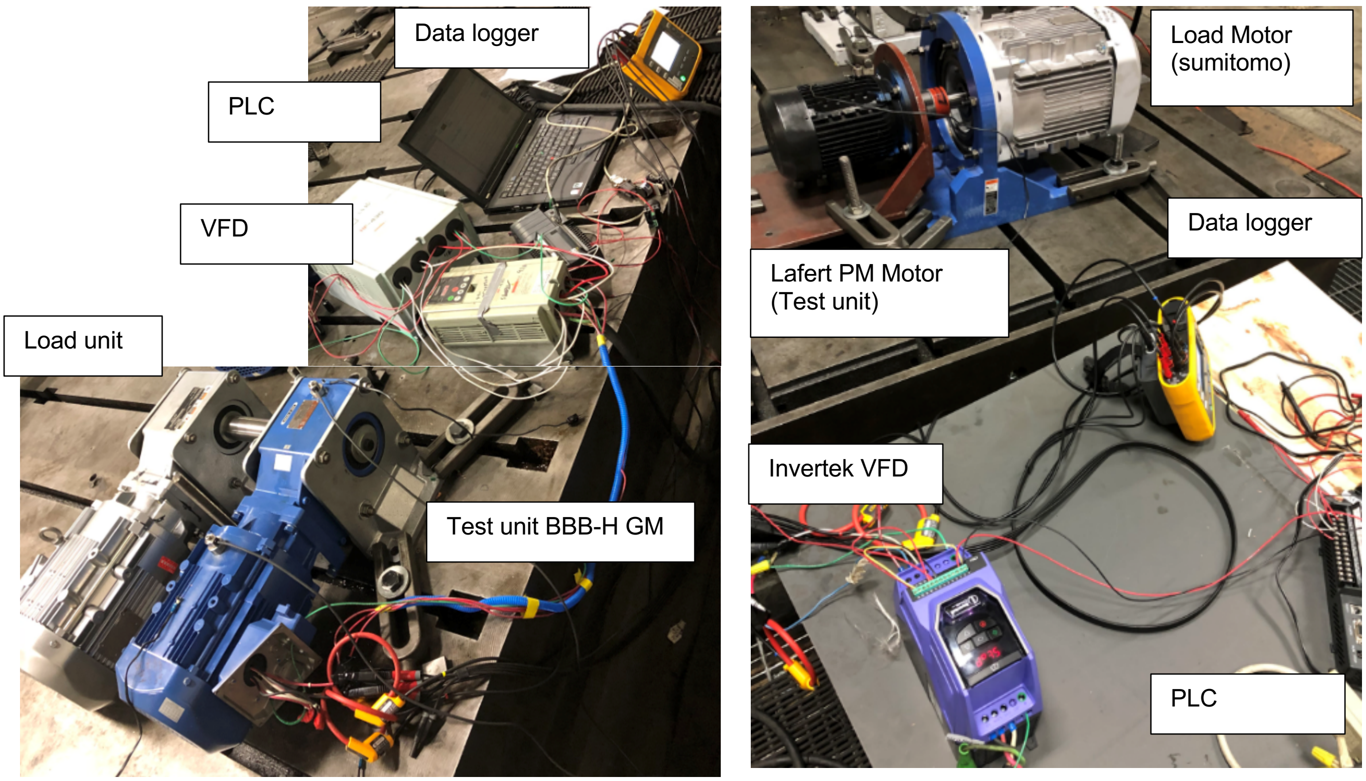
Criteria for Success:

1. Good or better condition of all mechanical wear components on the BBB-H reducer side as measured and judged qualitatively using AGMA Standards 932-A05[ix] and 1010-E95[x].
2. Quantitative measure of temperature rise and stabilization within normal design range.
3. Quantitative measure of Normal Amp Draw (confirming normal operation).

Temperature probes where connected to both the gearbox and motor frame. **Figure 10** shows the test setup for Test 1 and Test 2 respectively. Temperature was recorded every two to four minutes via data-logger. Amp-draw was also recorded (every second) via data-logger / analyzer software to quickly identify any adverse test condition either with the mechanical portion or the motor portion. Any abnormalities usually manifest themselves in amp-draw being too low (something has broken and is no longer transmitting torque), or too high, there is some binding or jamming that is occurring thus requiring more work out of the motor.
To prevent these situation, Sumitomo's Cyclo Smart® was being used to monitor and log the vibration. Should the system register any abnormalities, the motor power would be disconnected based the on setting limit on vibration level.

Figure 10 Test Setup

(a) Test 1 **(b) Test 2**



Test Results

Test 1 : BBB-H Gearmotor to Simulate Queue Conveyor Test

The test proceeded as designed. As noted, both Amp-draw and Temperature were measured and recorded without any detectable abnormalities. A typical amp-draw plot is shown in **Figure 11**. All parameters were deemed normal and within nominal range values and the data was accepted.

Figure 11 Test 1: Current Result

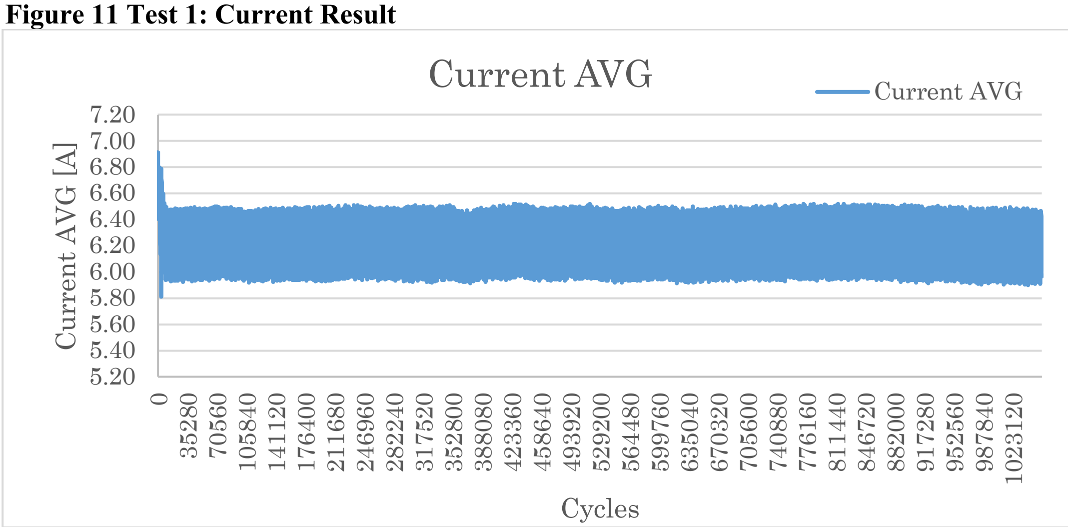
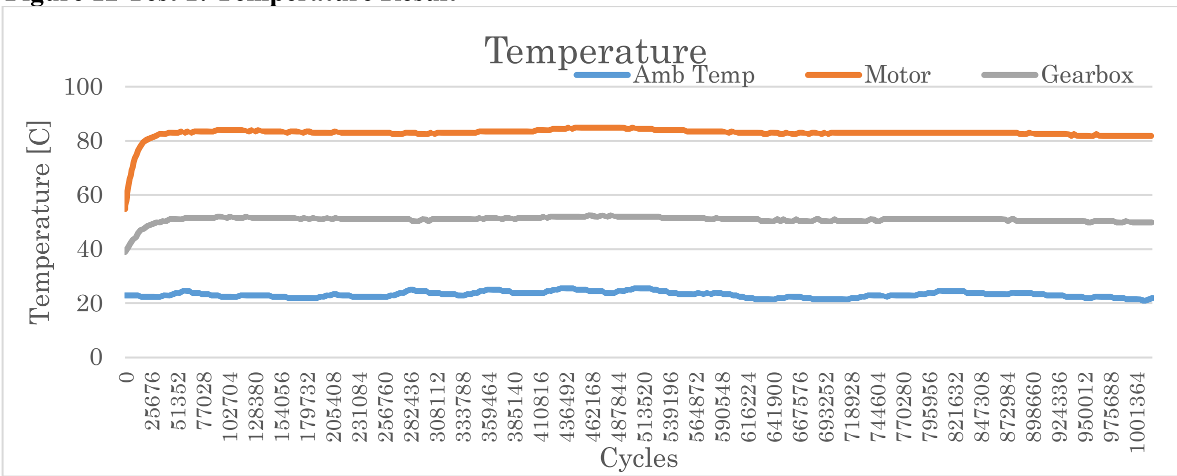


Figure 12 shows typical ambient and operating temperatures for both the mechanical reducer portion as well as the motor (frame) section for Test 1.

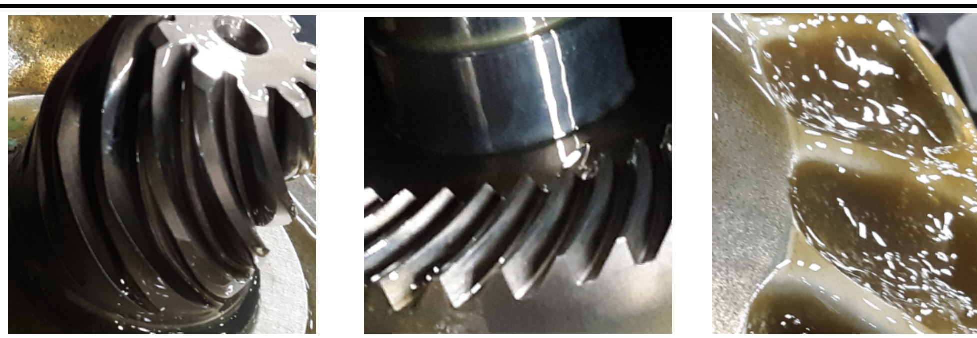
Figure 12 Test 1: Temperature Result



There were no abnormalities observed with the data and the general operation of the test. Both reducer and motor temperature magnitudes and differences (with ambient) were within nominal ranges and the data was confirmed and accepted. Coil resistance were check at the conclusion of the test and confirmed. Results were as match at 85ºC.

After the one millionth cycle and inspection of the mechanical components i.e. gears, pinion shafts, etc… were determined to be in and ideal condition. There was no indication of damage such as pitting, flaking, fretting corrosion, blacken, burnt, worn out or deterioration of any kind on any of the components.

Figure 13 Test 1: Reducer Main Componant Condition After 1 Million Start-Stop Cycles



(a) Bevel Pinion **(b) Bevel Gear** **(c) Grease Condition in Cover Sump (No blacken)**

Excellent	Good	Fair	Poor

Test 2 : Lafert IE5 PM Motor and Invertek VFD to Simulate Transport Conveyor Test

This test as well proceeded as designed. Both Amp-draw and Temperature were measured and recorded and all found in normal range. All parameters were deemed normal and within nominal range values and the data was accepted as showing **Figure 14.**

Figure 14 Test 2: Current Result

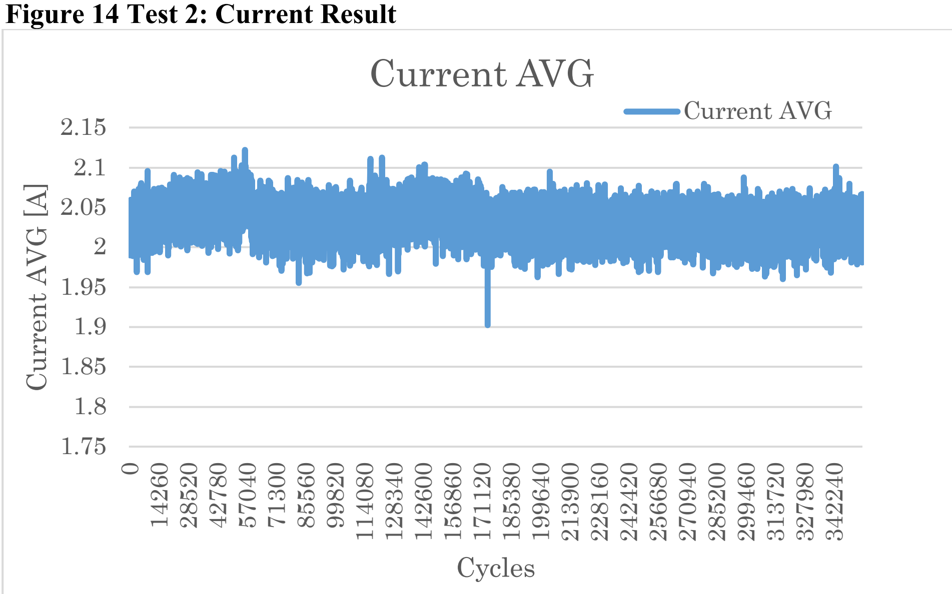
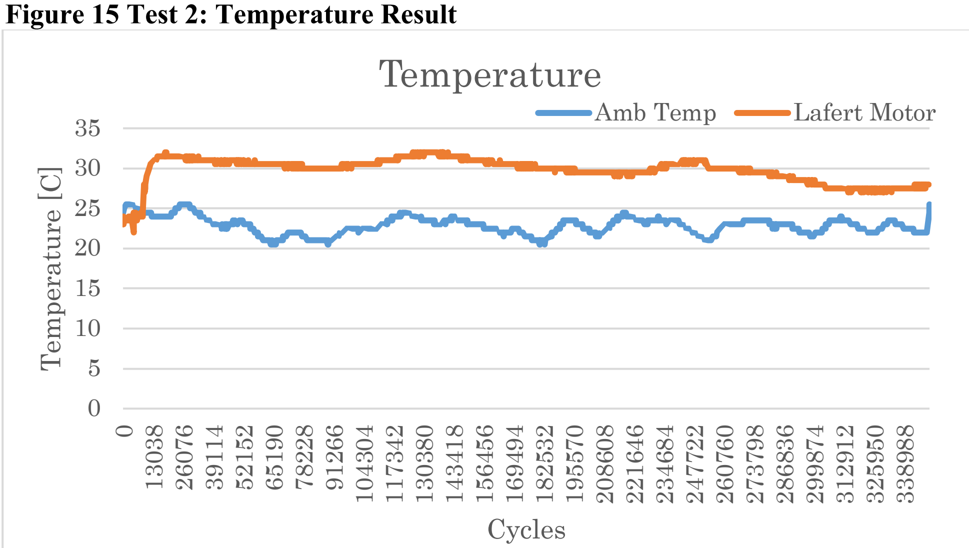


Figure 15 shows typical ambient and operating temperatures for Lafert Motor frame combined with Invertek VFD control. It is a plot of the actual data for a 0.3 million cycles and-monitoring the temperature stabilization. There were no abnormalities observed with the data and the general operation of the test. The Lafert motor temperature magnitudes and differences (with ambient) were within nominal ranges and the data was confirmed and accepted.

Figure 15 Test 2: Temperature Result



Test Conclusion

With this investigation, the objective was to test a potential solution that would meet and exceed the needs of ABH conveyor customers and end-users. Sumitomo Drive Technologies tested the BBB-H gearmotor and Lafert PM Motor with Invertek VFD combination. Focusing on both the mechanical and thermal characteristics of the entire package available from Sumitomo. Tests were based directly on test criteria developed for the industry and made known through customers and ABH Consulting firms. Simulation 1 conducted actual Queue Conveyor testing using Sumitomo integral gearmotor for application like **Figure 2** and **Figure 3**. **Figure 11** through **Figure** 15, illustrates the data using logger and analysis, which provided the ability to capture amp-draw and temperature result. For example on Queue Conveyor modeling test (Test 1), seeing the maximum motor temperature 85ºC confirmed by coil resistance method too, confirmed that the temperature rise of 65ºC by deducting ambient temperature of 22ºC average. The results were substantially better than motor insulation class regulation of NEMA electrical standard, comparing to 115ºC criterion on coil temperature at 'F' class insulation. The output gear and grease which are subjected to the greatest torque / loading values were also in excellent condition which has judged by following AGMA mechanical standard showed in **Figure** 13**.**

Studies

First study is thinking method of Mean Time Between Failure[xi] (MTBF) as per reliability system point of view. Such an aggressive cyclic operational pattern is demanded by Airport industry consultant firms as well as general customer in need of a reliable drive product. In the spirit of exceeding the customer expectation, drive products for the ABH Industry should possess a solution that is Maintenance free, conducive to automatic data logging ,through a continuous condition monitoring and IoT (Internet of Things) / CPS (Cyber Physical System) driven total technology – Industry 4.0 basis. MTBF and Reliability calculation are fundamental factors for industry. The basis of this test focused on ABH most common specification, designed as a system with an equipment life expectancy of a minimum of 15 years with cycle duty 18 hours per day, 365 days per year.

Test result from Test1 (Queue Conveyor modeling test) and method on MTBF and Reliability.

Load Definition

This calculation will be simulating the sample cycle showed in Figure 6 and 7, as accelerate from 0 fpm to 330 fpm in 0.35 seconds with a startup torque of 659 in-lbs. For the next 0.32 seconds the conveyor speed will be a constant 330 fpm with a running torque of 152 in-lbs. Next, the Queue conveyor will decelerate from 330 fpm to 0 fpm in 0.25 seconds with a braking torque of 557 in-lbs. At this time the Queue conveyor will dwell for approximately 0.08 seconds before restarting. The total cycle time for this index sequence will be (0.35 + 0.32 + 0.25 + 0.08= 1.0) one second. The total index distance is 54". This loading configuration represents a worst case scenario of 60 BPM with continuous staging. In typical airport operation would be an 18 hours run time day, and this time simulating two hours of indexing rush time for queuing and the remaining 16 hours queue conveyor will continuously run at 330 fpm with a constant running torque of 152 in-lbs which equates to a horsepower consumption of 0.83 hp. This definition is required every time depending on each an airport project and specification condition.

Equipment Life

The equipment life is basis of 15 years as above, operating 18 hours a day, 365 days per year. Therefore the equipment life equals 15 years x 365 days/year x 18 hours/day = 98550 hours

MTBF

The MTBF for the Gear Motor is based on the bearing life and the applied service factor for the gear motor. The formula used to determine this value is shown below. [xii]

MTBF = 5000 (hours) x $(SF_{GM})^3$

Because the Queue has two modes of operation (Indexing and Constant Speed), two respective values for MTBF were determined based on the service factor for each mode.

In an 18-hour day, two hours will be an indexing operation and the remaining 16 hours will be a constant speed operation.Therefore the equipment life for each mode will be as follows;

Equipment Life for Indexing = 98,550 (hours) x [2(hours) / 18(hours)]

EL_{Index} = 10950 (hrs)

Equipment Life for Constant Speed = 98,550 (hours) x [16(hours) / 18(hours)]

EL_{Const} = 87600 (hours)

Next the HP requirements for each mode were determined as follows;

HP for Indexing = T_{max} x RPM_{avg} x SF_{motor} / 63025

HP_{Index} = 659(in-lbs) x 150.5 (rpm) x 1.15 / 63025 = 1.8 HP

HP for Constant Speed = T x RPM_{max} x SF_{motor} / 63025

HP_{Const} = 152(in-lbs) x 301 (rpm) x 1.15 / 63025 = 0.83 HP

The rated input horsepower for the BBB-H geared motor is 3.8 HP at 750 rpm motor input and 7.4 HP at 1505 rpm motor input (i.e. Max Speed 301rpm = 1505rpm / ratio 5). Therefore the service factor (SF_{GM}) for each mode of operation was determined as follows;

SF_{GM} for Indexing = 3.8 HP / 1.8 HP = 2.11

SF_{GM} for Constant Speed = 7.4 HP / 0.83 HP = 8.92

Substituting the SF_{GM} for each mode into the MTBF formula above yields the following;

$MTBF_{Index}$ = 5000 (hrs) x $(2.11)^3$ = 46970 (hours/failure) > EL_{Index} = 10950 (hrs) - - - OK

$MTBF_{Const}$ = 5000 (hrs) x $(8.92)^3$ = 3548661 (hours/failure) > EL_{Const} = 87600 (hrs) - - - OK

System Reliability

According to Reliability Engineering, MTBF and MTTF (Mean Time To Failure) are the important factors for evaluating equip component reliability and MTBF can express below formula in case the Failure Rate (λ) is constant. [xiii]

MTBF = 1 / λ $\therefore \lambda$ = 1 / MTBF

Therefore the Failure Rate for the entire Equipment Life (98550 hrs) is;

Failure Rate per Equipment Life = EL_{Index} / $MTBF_{Index}$ + EL_{Const} / $MTBF_{Const}$
= 10950 (hrs) / 46970 (hours/failure) + 87600 (hrs) / 3548661 (hours/failure)

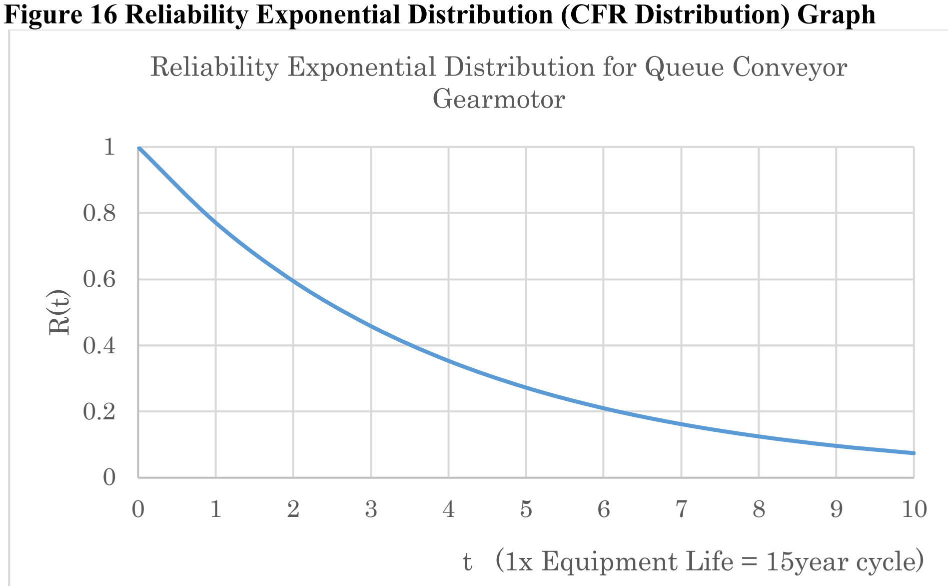
Failure Rate per Equipment Life = **0.26 failures**

The Degree of Reliability to be expressed by below formula;

$R(t) = e^{-\lambda t}$

Therefore, the exponential distribution as reliability calculation per Equip life would be;
(t stands for an Equipment life = 15 year each)

Figure 16 Reliability Exponential Distribution (CFR Distribution) Graph



After 1 Equipment life (15-year cycle), the probability of reliability to be 77% in good condition.

Finally, this point merits particular consideration based on close discussions with key ABH consultants and their concern of motor bearing fluting and pitting. Such an issue would be indicative of shaft current flow and travel through motor bearings when VFDs are utilized. Error! Reference source not found. shows Capacitive EDM (Electrical Discharge Machining) currents and **Figure 18** shows its shaft voltage discharge causing current flow through bearing confirmed by Fuji Electric Japan. This phenomenon must be avoided to prevent bearing fluting. Vibration and bearing noise increases with the appearance of fluting and pitting; and if the bearings are not replaced after a reasonable amount of time, complete failure may occur. Based on proper grounding and design Sumitomo has never experienced this type of failure and this time we have checked shaft voltage which is causing the current loss thru bearing.

Figure 17 Shaft Current[xiv]

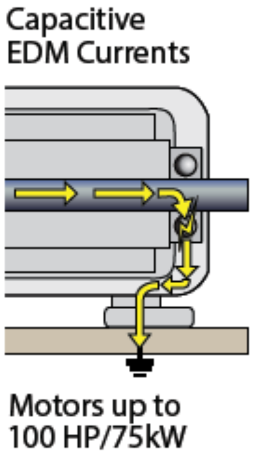


Figure 18 Capacitive Electrical Discharge[xv, xiv]

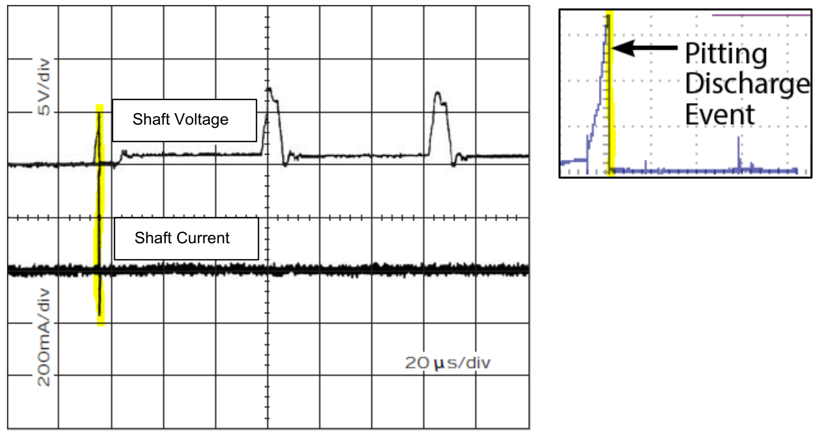


Figure 19 shows test condition of Lafert PM motor and Invertek VFD combination to measure shaft voltage. Results shown in **Figure 20**, confirm that no indication of shaft voltage charged were present, which means there will be no immediate current threshold or peak to the motor bearing and earthing. NEMA MG1 Part 31.4.4.3 identifies capacitive shaft voltages of 10 to 40 volts peak (or 20 to 80 volts peak-to-peak) as a level which could cause electrical discharges in a motor's bearings[xiv] and the value of result expressed only 1.5 volts (500 mV per div. in Figure 20). The same test were conducted with Sumitomo IE3 induction motor, yielding favorable results. Insulation grounding ring equip to motor shaft is commercially available solution to this phenomenon, however, Sumitomo motor and Lafert motor with Invertek VFD combination proved that does not required such additional installation.

Figure 19 Lafert Motor and Invertek VFD Test

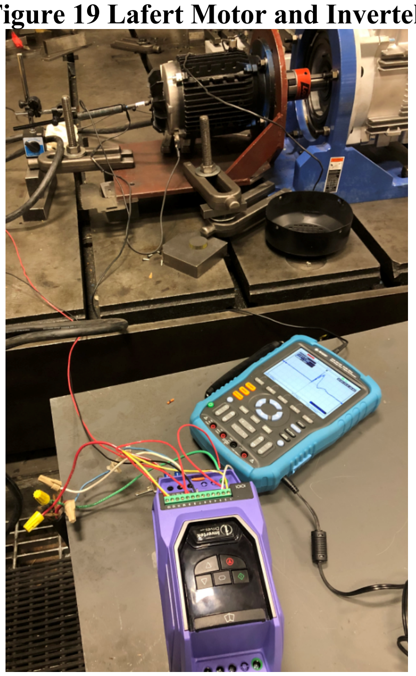
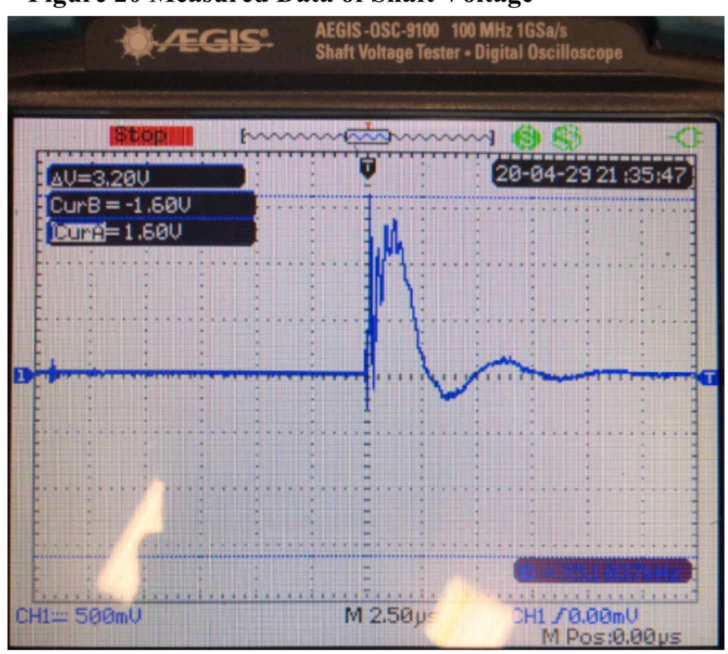


Figure 20 Measured Data of Shaft Voltage



Summary

Based on all our test data, both qualitative, as well as quantitative, we can conclude that the units tested passed all expectation in terms of performance as measured to direct industry mechanical (AGMA) as well as Electrical (NEMA) standards and specifications. The units are very well-suited for the baggage-handling conveyor application, and working closely with them in order to test to actual conditions. If properly selected Sumitomo Drive Technologies expects their BBB-H Gearmotor Series units, Lafert IE3 PM motor and Invertek VFD drive to perform problem-free and virtually maintenance-free, longer MTBF in this application and these combination truly provide customers with long-term success and flexibility.

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