## **LNG TANDEM OFFLOADING SYSTEM**

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## **1.0 ABSTRACT**

FMC Energy Systems has combined two industry proven technologies to create the safest and most reliable tandem LNG loading/offloading system available to the offshore industry. The LNG Tandem Offloading System, which is capable of transferring LNG at a rate of 15,000 m<sup>3</sup>/hr, is comprised of two totally independent systems, the LNG transfer system and the mechanical mooring system.

The LNG transfer system utilizes industry proven LNG transfer technology from FMC Loading Systems in France. It provides simple LNG connection by vertically suspending the LNG Chiksan loading arms system, a double pantograph comprised of four sixteen-inch product lines, from a fixed outboard boom.

The mechanical mooring system uses a robust duplex yoke that minimizes the sway motions between vessels to maximize the FPSO's ability to offload in harsh weather locations. This new concept in mooring yoke technology decouples lateral stiffness from fore and aft stiffness resulting in a dual, or duplex action. This duplex yoke, made by FMC SOFEC Floating Systems, moors the vessels using a combination of industry proven yoke and high load connector technology. The mechanical mooring system is connected using a simple and safe procedure that minimizes assistance from auxiliary vessels. The duplex yoke has been very successful in wave basin model testing as well as extensive computer simulation.

Fully integrated, these two systems have resulted in an excellent combination of proven technologies. This paper will discuss the evolution of FMC Energy Systems' LNG Tandem Offloading System, the major design features, as well as relevant project experience relating to tandem LNG offloading.

## 2.0 BACKGROUND OF LNG TRANSFER SYSTMES

When transferring LNG, there are many variables that limit the options available for designing the structure. A few examples of these variables include: types of ships, mooring variations, water level variations (tides), and wave conditions. These variables help define the operating envelope of the transfer system. The larger the operating envelope, the stronger the system must be in order to function properly in the dynamic conditions. A representation of the operating envelope is shown below in *Figure 1*. However, the most limiting factor in LNG transfer systems is the relative motions of the flanges during connection.



### 2.1 ONSHORE, PROTECTED

The most common type of loading facility is an onshore facility that is connected via a jetty and ship-berthing and mooring dolphins. These facilities are in very benign waters or they have a breakwater. The relative motions during connection of the flanges would be small:

- Vertical Displacement +/- 0.1 m
- Horizontal Displacement +/- 0.1 m
- Velocity +/- 0.05 m/s
- Acceleration +/-  $0.025 \text{ m/s}^2$

The typical installation would include 3 to 5 loading arms (2 to 4 liquid and 1 vapor) to unload a gas carrier at rates ranging from 4,000 to 12,000 cubic meters per hour  $(m^3/hr)$ . These loading arms also vary in size from 8" to 24" in diameter and usually include emergency release systems, manual couplers, and position monitoring systems.

### 2.2 ONSHORE, EXPOSED

Due to the high costs of a breakwater, some onshore installations are exposed to slightly more turbulent waters. These facilities, while similar to protected onshore facilities, have larger relative motion requirements for connecting the flanges:

- Vertical Displacement +/- 0.5 m
- Horizontal Displacement +/- 0.5 m
- Velocity +/- 0.25 m/s
- Acceleration +/-  $0.125 \text{ m/s}^2$

These larger motions dictate that the exposed offshore facilities use loading arms that have constant motion swivels and a hydraulic coupler rather than manual couplers. The arms typically include emergency release systems and position monitoring systems.

## 2.3 OFFSHORE (SHIP TO SHIP)

Offshore LNG introduces many operational and logistical challenges that must be compensated for in the design of the facility. However, the financial benefits of recovering stranded gas or offloading to a regasification barge have driven new developments in floating LNG.

<u>Side-by-Side</u> - One development in offshore LNG is the side-by-side arrangement developed by FMC Energy Systems. This system is comprised of a dynamic loading arm and a targeting system. The maximum relative flange movements during connection are:

- Vertical Displacement +/- 2.5 m
- Horizontal Displacement +/- 1.7 m
- Velocity +/- 1.0 m/s
- Acceleration +/-  $0.5 \text{ m/s}^2$

This range of motion requires a cable assisted connection system for each of the 3 arms (2 liquid and 1 vapor). The connections are made by maneuvering the arms over the LNG carrier's manifold and dropping a messenger line. The line then guides the arm into the proper alignment. *Figure 2* below shows the connection sequence.





<u>Boom to Tanker</u> - Another variable that limits the options for designing an offshore facility is the percent availability of the facility. For an FPSO or regasification barge, limited LNG storage requires that the facility must have a high percent availability of LNG transfer. Therefore the vessel may sometimes offload to a carrier in relatively harsh conditions.

One solution that FMC Energy Systems has developed for this situation is the FMC Boom to Tanker. This system utilizes a pantograph that is vertically suspended from a

boom. The pantograph is capable of transferring LNG at a rate of 10,000m3/hr and is comprised of one liquid arm (24") and one vapor arm (16"). The LNG carrier is moored using two hawser lines that are kept in tension with the reverse thrust of the carrier. The crane boom system is mechanically operated to follow the lateral movements of the carrier to ensure the LNG pantograph remains within its 23.0m diameter operating envelope. The relative flange movements during connection are:

- Vertical Displacement +/- 5.0 m
- Horizontal Displacement +/- 5.0 m
- Velocity +/- 2.5 m/s
- Acceleration  $\pm -2.5 \text{ m/s}^2$

The FMC Boom to Tanker system requires a targeting system similar to that of the sideby-side arrangement. The pantograph is equipped with an emergency release system, hydraulic couplers, constant motion swivel joints and a position monitoring system. A  $1/5^{th}$ -scale model, shown below in *Figure 3*, has been built and successfully tested in Sens, France. The rest of this paper discusses another viable solution to the offloading of LNG in relatively harsh weather conditions.



#### Figure 3: Boom to Tanker Model

# 3.0 LNG TANDEM OFFLOADING SYSTEM

FMC Energy Systems has developed a proprietary LNG Tandem Offloading System specifically for harsh weather environments. This system is the combination of two independent industry-proven technologies that results in the safest and most reliable tandem LNG loading/offloading system available to the offshore industry. The LNG Tandem Offloading System, which is capable of transferring LNG at a rate of 15,000  $m^3/hr$ , is comprised of two totally independent systems, the LNG transfer system and the mechanical mooring system. A representation of the LNG Tandem Offloading System is shown below in *Figure 4*.



Figure 4: LNG Tandem Offloading System

The Tandem Offloading System uses a duplex yoke to limit the motion of the carrier and a double pantograph to offload the LNG. This system does not require hawser lines or stern thrust during the offloading operation. LNG carriers can be purpose built with the bow connection assembly or an existing carrier can be readily converted without the need for dry-docking. The modifications do not interfere with the existing OCIMF bow mooring equipment.

### **3.1 MOORING SYSTEM**

The mechanical mooring system uses a robust duplex yoke that minimizes the sway motions between vessels to maximize the FPSO's ability to offload in harsh weather conditions. This new concept in mooring yoke technology decouples lateral stiffness from fore and aft stiffness resulting in a dual, or duplex action. This duplex yoke, made by FMC SOFEC Floating Systems, moors the vessels using a combination of industry proven yoke and high load connector technology. The mechanical mooring system is connected using a simple and safe procedure that minimizes assistance from auxiliary

vessels. The duplex yoke has been very successful in wave basin model testing as well as extensive computer simulation. The environmental design criteria for the yoke is shown in *Table 1* below.

		100-Year Seastates			99.40%	
		Wave Only	Crossed 1	Crossed 2	Connection	
Water Depth		64	64	64	64	m
Wave						
	Wave Spectral Model	P-M	P-M	P-M	P-M	
	Significant Wave Height	5.5	5.5	5.5	3.5	m
	Peak Period	12	10.5	12	9.5	sec
	Direction	180	180	180	180	deg
Wind	Velocity		42.9	42.9	23.5	knots
	Wind Spectral Model		API	API	API	
	Direction		225	225	225	deg
Current	Velocity		1.45	1.45	0.58	knots
	Direction		270	270	270	deg

Table 1: Design Criteria

<u>Conventional Yokes</u> - Traditionally, yoke moorings have been used to permanently moor FSOs and FPSOs in shallow water. They permit the vessel to move in response to the environmental conditions while limiting the vessel's surge motions and maintaining a safe distance between the FSO/FPSO and the mooring platform.

However, utilizing a conventional yoke for a tandem offloading mooring would not adequately reduce the swaying motion of the carrier and as a result, a crane boom would be required to mechanically follow the carrier to ensure the LNG transfer system would remain within a safe operating envelope. An example of a conventional soft yoke is pictured below in *Figure 5*.



Figure 5: Conventional Soft Yoke

<u>Duplex Yoke</u> - The duplex yoke is a new concept in yoke mooring technology. Essentially, it is a mechanical linkage that decouples the lateral stiffness from the fore and aft stiffness of the carrier. By using the counterweight coupled with the articulated linkage, the yoke exerts a force in a dual, or duplex action. The result is an increase in lateral stiffness several times that of a conventional soft yoke while maintaining the same fore and aft stiffness. *Figures 6* and 7 below show the duplex yoke just prior to connection.



<u>Connection and Disconnection</u> - The LNG Tandem Offloading System moors the LNG carrier using simple procedures and minimal, if any, assistance from auxiliary vessels. As the LNG carrier approaches the LNG facility, two hawser lines are connected to the bow of the carrier and are used for winching the carrier in closer to the LNG facility. Once these lines are established, the LNG carrier uses reverse thrust to ensure vessel separation. Next, the carrier is winched closer to the FPSO until the vessel is close enough to reach the yoke retrieval line. The vessel is then winched closer via the hawser and the yoke retrieval line. *Figures 8* and 9 below show a representation of the connection sequence.









The cone enters the mating cone connection module and locks the yoke into place. The process and winches are controlled from the FPSO. At this stage, the carrier is ready to connect the LNG transfer system. Disconnection is the same sequence done in reverse.

<u>Model Basin Testing</u> - In November of 2002, the LNG Tandem Offloading System was tested in a model basin at the State Key Laboratory of Ocean Engineering in Shanghai, China. The model LNG carrier and FPSO dimensions were scaled to the vessel specifications listed in *Table 2* below.

	LNG Carrier	LNG FPSO	
LNG Capacity	142,000	240,000	<b>Cubic Meters</b>
Displacement	114,465	168,220	Metric Tons
Length of vessel at waterline	270.8	300.0	Meters
Beam of vessel at waterline	45.3	54.5	Meters
Vessel draft	11.3	12.5	Meters
Heave Period	9.8	11.4	Seconds
Roll Period	14.2	14.0	Seconds
Pitch Period	10.4	11.2	Seconds

 Table 2: Vessel Specifications

The results of the model basin testing successfully demonstrated the design of the mooring system. The duplex yoke controlled the relative motions within an operating envelope acceptable for the LNG transfer system.

## **3.1 LNG TRANSFER SYSTEM**

The LNG transfer system utilizes industry proven LNG transfer technology from FMC Loading Systems. It provides an LNG connection by vertically suspending the LNG Chiksan Loading Arms, arranged in a double pantograph, from a fixed outboard boom.

<u>Double Pantograph</u> - The LNG transfer system uses 4 product lines, each 16 inches in diameter, to transfer the LNG at a rate of 15,000m3/hr. The product lines are configured in a double pantograph formation that allows them to retract, extend, and rotate in a motion similar to a pendulum of a clock from port to starboard as well as fore and aft. The pantograph uses industry proven swivel joints and quick connects/disconnects. Maintenance can be performed anywhere on the pantograph, while at sea, using a service platform that moves along the boom. A representation of both the pantograph and the service platform are shown below in *Figures 10* and *11*.

Figure 10: Double Pantograph







<u>Connection and Disconnection</u> – To connect the product lines, the operator located on the shuttle carrier lowers a messenger line, similar to the side-by-side system, to connect the

acquisition cable. This acquisition cable is used to lower the double pantograph system to the manifold system, depicted in *Figure 12* to the right, located on the LNG shuttle carrier bow. To avoid any shock, the heave of the vessels is compensated by managing the tension in the double pantograph cables. The centering device consists of a male and a female cone to secure the connection. An independent mechanical coupler is used to take all the loads applied on the pantograph system.





Once the mechanical coupler is locked, the operator moves the two jumper assemblies to align them with the LNG quick connect/disconnect couplers. The hydraulic cylinders raise the ball valves of the LNG carrier in front of the couplers for the final connection of the product lines.

Disconnection is basically the reverse of the connection sequence. When the pumps are stopped and the LNG piping drained with dry nitrogen gas, the operator then proceeds to disconnect. Interlocks forbid the release of the product couplers before the ball valves are closed. After the disconnection of the product couplers, the mechanical system can be released and the double pantograph system is raised while the heave compensation system is automatically engaged. To ensure optimal operating flexibility, emergency disconnection from the carrier is totally independent of the duplex yoke.

# 4.0 THE NEXT STEPS

Over the next six months, FMC Energy Systems will continue to develop the LNG Tandem Offloading System working diligently in the following areas:

- Scale model testing of the yoke cone connector equipment
- Development of detailed installation and operational procedures
- Conduction of a comprehensive safety and risk analysis
- Obtain "Approval in Principle" or other certifications as appropriate (one or more from Lloyds, ABS, DNV or BV)